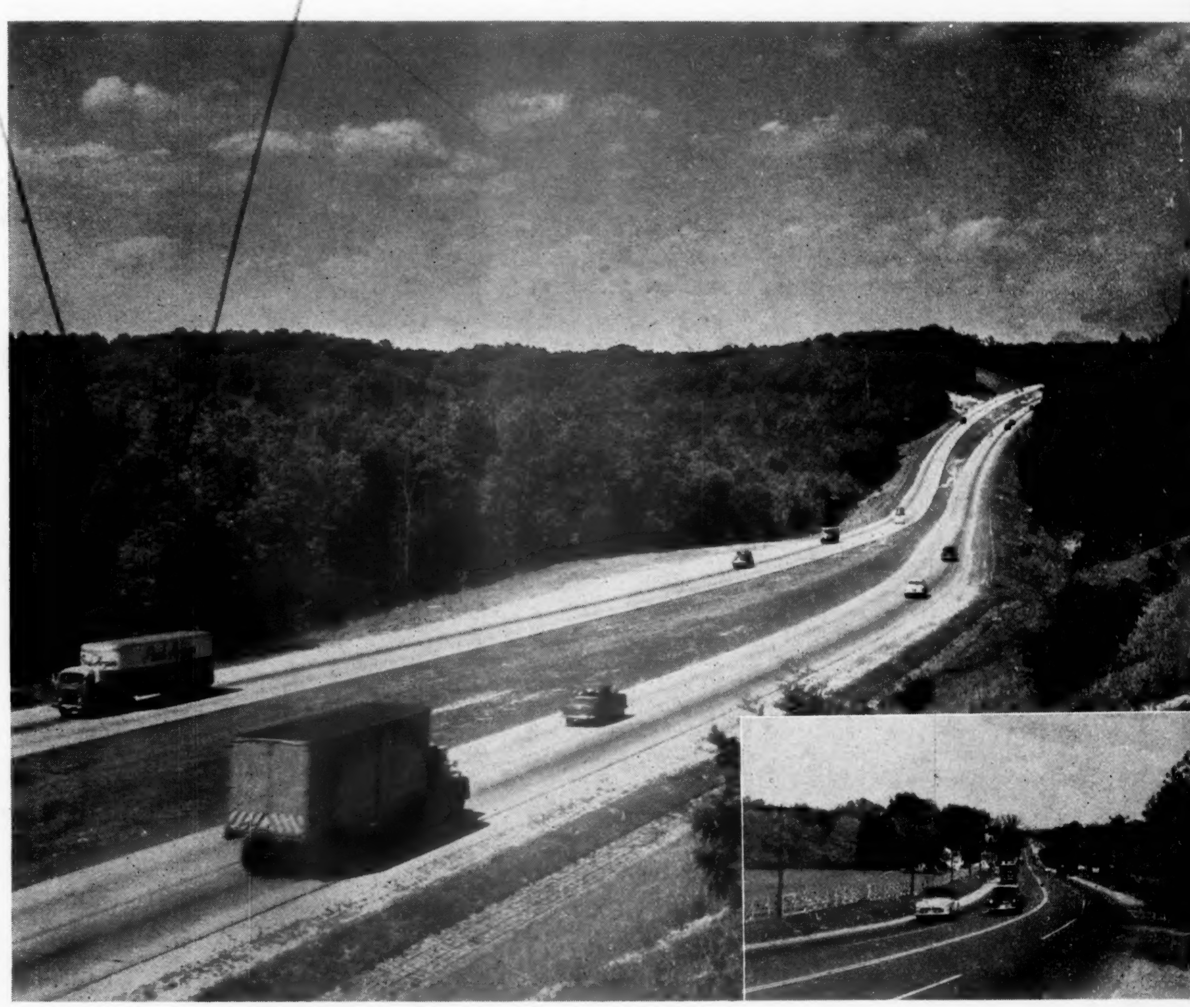
VOL. 28, NO. 9 AUGUST 1955



# Public Roads

A JOURNAL OF HIGHWAY RESEARCH





PUBLISHED BY
THE BUREAU OF
PUBLIC ROADS,
U. S. DEPARTMENT
OF COMMERCE,
WASHINGTON

In this issue: Passenger car performance on selected routes
(Shirley Memorial Highway and inset of U. S. 1 in Va.)

# Public Roads

A JOURNAL OF HIGHWAY RESEARCH

*Vol. 28, No. 9* *August 1955*

*Published Bimonthly*

Edgar A. Stromberg, *Editor*

# IN THIS ISSUE



U. S. DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

BUREAU OF PUBLIC ROADS
CHARLES D. CURTISS, Commissioner

BUREAU OF PUBLIC ROADS

Washington 25, D. C.

DIVISION OFFICES

No. 1. 718 National Savings Bank Bldg., Albany 7, N. Y.
*Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.*

No. 2. 707 Earles Bldg., Hagerstown, Md.
*Delaware, District of Columbia, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia.*

No. 3. 50 Seventh St., N. E., Atlanta 5, Ga.
*Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Puerto Rico.*

No. 4. South Chicago Post Office, Chicago 17, Ill.
*Illinois, Indiana, Kentucky, Michigan, and Wisconsin.*

No. 5. Federal Office Bldg., Kansas City 6, Mo.
*Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.*

No. 6. 502 U. S. Courthouse, Fort Worth 2, Tex.
*Arkansas, Louisiana, Oklahoma, and Texas.*

No. 7. Old Mint Bldg., San Francisco 3, Calif.
*Arizona, California, Nevada, and Hawaii.*

No. 8. 753 Morgan Bldg., Portland 8, Oreg.
*Idaho, Montana, Oregon, Washington, and Alaska.*

No. 9. Denver Federal Center, Bldg. 40, Denver 2, Colo.
*Colorado, New Mexico, Utah, and Wyoming.*

PUBLIC ROADS is sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at $1 per year (25 cents additional for foreign mailing) or 20 cents per single copy. Free distribution is limited to public officials actually engaged in planning or constructing highways, and to instructors of highway engineering. There are no vacancies in the free list at present.

The printing of this publication has been approved by the Director of the Bureau of the Budget, March 17, 1955.

# Operating Characteristics of a Passenger Car on Selected Routes

*BY THE HIGHWAY TRANSPORT RESEARCH BRANCH*
*BUREAU OF PUBLIC ROADS*

**Reported by CARL C. SAAL**
**Chief, Vehicle Operations Section**

***To obtain data on the performance of typical automobiles under various highway operating conditions, a representative passenger car was driven some 28,000 miles on nine distinct studies during 1951 and 1952. The car was equipped with instruments to record the amount of time it operated at various speeds, rates of deceleration, percentages of maximum engine torque, and percentages of full throttle opening; the total fuel consumption and the amount of fuel used at various speeds; and the total trip time.***

***Five of the nine studies compared operations over a freeway having full control of access with grade separations and operations over a parallel major highway with intersections at grade and direct access to abutting property. The other studies were of a special nature made to evaluate the effect of traffic signals, sight distance, grade separation, and traffic congestion on the vehicle operational characteristics.***

***The data which were developed show some of the road-user benefits that may result through the use of a freeway instead of a parallel major highway, and establish basic relations between fuel consumption and highway gradient. The report also indicates the extent to which certain built-in vehicle characteristics are used in normal operation and discusses the relative advantages, in terms of fuel savings, of two methods commonly used to reduce gradients.***

A KNOWLEDGE of certain operating characteristics of motor vehicles is essential in the development of standards and specifications for highways and for vehicles that will provide for the safe and efficient movement of traffic. In order to obtain data on the performance of typical passenger cars under varying highway operating conditions, the Committee on Vehicle Characteristics of the Highway Research Board, assisted by industry and government, developed instruments to record for any trip the amount of time that a vehicle operates at various speeds, rates of deceleration, percentages of maximum engine torque, and percentages of full throttle opening; the total fuel consumption and the amount of fuel used at various road speeds; and the total trip time.

The Bureau of Public Roads has made extensive use of these instruments to determine how these vehicle characteristics for a typical passenger car are related to various types of highway operations. A representative passenger car was operated some 28,000 miles on nine distinct studies during 1951 and 1952. Five of the nine studies dealt with operations over a freeway and over a parallel major highway. The other studies were of a special nature made to evaluate the effect of traffic signals, sight distance, grade separation, and traffic congestion on the vehicle operational characteristics.

This report is concerned essentially with the results of the studies which involved freeway operation. However, it covers briefly the studies of a special nature, and includes the results of special tests made to determine the fuel consumption and accelerating characteristics of the test vehicle on individual grades. The results reported here supplement those obtained by other investigators with the same set of instruments.

Although the basic data should have use in the fields of highway economics and design and within certain areas of automotive engineering, it is cautioned that the data represent only the performance of one 1951 model passenger car operated by the same driver throughout the tests. It may be farfetched to consider the performance data as representative of the average performance of passenger cars operating in the general traffic. On the other hand, it is believed that the performance of the test car on highway sections of varying geometric design may be compared to establish a relation which will be fairly representative of the relative performance of the average passenger car. Also, the relations established between fuel consumption, speed, and other variables may be reliably used to determine the relative advantages of various methods of reducing grades and estimating the fuel consumed on a given highway section.

### *Terminology*

In order that there be a clear understanding of the discussions in this report, terms frequently used are here defined.

*Freeway.*—A divided arterial highway for through traffic with full control of access and with grade separations at intersections.

*Major street or major highway.*—Usage here is limited to arterial highways with intersections at grade and direct access to abutting property, and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.

*Overall travel time.*—The time of travel, including stops and delays except those off the traveled way.

*Overall travel speed.*—The speed over a specified section of highway, being the distance divided by overall travel time. The average for all traffic, or component thereof, is the summation of distance divided by the summation of overall travel times.

*Composite performance.*—The performance in given terms for a round trip over a specified section of highway. (Composite gasoline consumption in gallons per mile is the total number of gallons of gasoline required by a vehicle to travel in both directions on a section of highway, divided by twice the length of the section in miles.)

*Directional performance.*—The performance in given terms in a single direction over a specified section of highway.

*Road-user benefits.*—The advantages or savings that accrue to drivers or owners through the use of one highway facility as compared with the use of another. Benefits are measured in terms of the decrease in road-user costs and the increase in road-user services.

*Total rise and fall.*—The arithmetic sum of the vertical rise and fall in feet for any section of highway. (If the section of highway progressively rises 100 feet, falls 500 feet, rises 30 feet, and falls 10 feet, the total rise and fall will be 640 feet. The total rise and fall is the same regardless of the direction of travel.)

*Rate of rise and fall.*—The total rise and fall for any section of highway divided by the length of section in hundreds of feet. (It is

not to be confused with the percent of grade. It is equivalent to the average percent of grade only when either the rise or fall is 100 percent of the total rise and fall.)

*Average test method.*—The driver travels at a speed which in his opinion is representative of the speed of all traffic at the time, without trying to keep a balance in the number of passings.

*Attempted speed test method.*—The driver attempts to maintain a specified speed over a section of highway, passing all vehicles that interfere with maintaining the specified speed, and exceeding the specified speed only during the passings.

*Maximum torque.*—The maximum engine torque at a specified engine speed or corresponding road speed.

## *Purpose of Report*

The specific purposes of this report are as follows: To show some of the road-user benefits that may result through the use of a freeway instead of a parallel major highway, to determine the extent to which certain built-in vehicle characteristics are used in normal operation, to establish basic relations between fuel consumption and highway gradient, and between acceleration and highway gradient, to evaluate several methods used to estimate the fuel consumed on a highway section, and to determine the relative advantages, in terms of fuel savings, of two methods commonly used to reduce gradients.

## *Summary of Findings*

The pertinent findings described here refer specifically to the operations of the test passenger car. Definite conclusions as to the overall performance of passenger cars in the general traffic cannot be formed from the results of tests on a single passenger car operated by the same driver on all tests. Only indications of the overall performance of passenger cars should be read into any of the findings.

1. For each of the five freeway studies, considering the total lengths, the test car would have had to travel over the freeway at a slower speed than the average overall travel speed reported for all passenger cars using the facility, in order to realize the same rate of fuel consumption as observed on the parallel major highway. Therefore, if the test car were to maintain prevailing overall travel speeds on comparable roads, the consumption per mile would be higher on each freeway than on the parallel major highway.

2. Unless a major highway has a much greater rate of rise and fall or is much more congested than a parallel freeway, the latter will show a higher rate of consumption when the vehicle is operated at the average overall travel speeds found on the two roads. For example, the consumption per mile at the prevailing average overall travel speeds was lower on the western extension of the Pennsylvania Turnpike than on the highly urbanized section of the parallel route extending through Wilkinsburg and Pittsburgh, Pa.

3. A sizable time savings resulted in each case from the use of a freeway, instead of a major highway, at the average overall travel speeds found on the two roads.

4. Except in one case, the use of the freeway instead of the parallel major highway saved enough travel mileage to make the fuel consumption in gallons approximately the same for a composite trip over either facility when the vehicle was operated at the average overall travel speeds found on the two roads.

5. Where the average overall travel speed on a freeway was below 40 miles per hour, the use of such facility instead of a major highway showed sizable savings in gasoline during the peak traffic periods.

6. The percentage of time spent in braking was nearly zero on a freeway and very small on a major highway; however, the time spent in braking on a major highway was as much as 34 times greater than that spent on a freeway. The maximum rate of deceleration recorded on any test was about 60 percent of the potential rate of deceleration built into the car.

7. Maximum engine torque and full throttle opening were used only a very small portion of the time on either a freeway or a major highway. Less than half of the potential torque and power were normally utilized on any test run. The average engine torque and throttle opening observed on a major highway were appreciably less than that observed on the parallel freeway at the average overall travel speeds found on the two roads.

8. The relations established between fuel consumption and rate of grade, and between fuel consumption and rate of rise and fall were very similar. In general, the rate of consumption increases about in direct proportion to the increase in grade or rate of rise and fall up to 6 percent. Above 6 percent, the increase is at a faster rate.

9. A reduction of grades exceeding 6 percent resulted in appreciable savings in fuel consumption, whether or not the reduction involved a decrease in rise and fall. However, reduction of grades between 4 and 6 percent produced no substantial savings unless the grade reduction also reduced rise and fall. A reduction of 3- and 4-percent grades did not result in an appreciable savings, even if rise and fall was also reduced.

10. The use of the rate of total rise and fall of a section of highway to estimate fuel consumption on the section was found to be as accurate as a more complicated method that involved the consideration of each individual grade.

## *Scope of Studies*

### Freeway studies

In selecting the five pairs of test routes for studying some of the road-user benefits that might result from the use of freeways by passenger cars, an effort was made to cover as wide a range of highway conditions as possible in the Eastern United States. The five freeways selected for study were the New Jersey Turnpike, the middle section of the Pennsylvania Turnpike, the Maine Turnpike, the western section of the Pennsylvania Turnpike, and the Shirley Memorial Highway in Virginia. Only the latter route was free of toll. The parallel major highway in each instance was the alternate route that would be commonly used to travel between the same termini.

Figures 1 through 5 show sketches of the general layout of the test routes for each study and the profiles for each pair of routes, except for the Maine Turnpike study. These profiles were plotted from elevations measured with an altimeter. Each of the routes, except the western section of the Pennsylvania Turnpike, was divided into test sections by control points located at definite changes in the character of the profile or traffic flow. The operating characteristics of the test vehicle, within each section, were recorded at these control points.

All of the freeways were built approximately to the same design standards. The maximum grade was not over 3 percent in any case, and the rate of rise and fall varied from 0.8 for the New Jersey Turnpike to 1.4 for the two sections of the Pennsylvania Turnpike. It could be expected that the test car would perform about the same on each of the five freeways.

In contrast each route paralleling a freeway afforded a conglomeration of surface types, pavement widths, curvatures, and gradients. There was also considerable variation in the design characteristics between the various parallel routes. The rates of rise and fall varied from 0.9 for the route paralleling the New Jersey Turnpike to 3.3 for the route paralleling the middle Pennsylvania Turnpike. The parallel major highway and the turnpike had approximately the same rate of rise and fall in the case of the New Jersey and Maine studies. The rates of rise and fall for the routes paralleling the middle and western sections of the Pennsylvania Turnpike, and the Shirley Memorial Highway were about 2.4, 1.4, and 1.3 times that for the respective freeway. In addition to the wide range in the character of the profiles, the routes paralleling the freeways differed materially from each other in other ways which had a bearing on the results obtained. This can best be brought out by a brief description of each parallel major highway.

Generally, the parallel major highway in New Jersey was of four-lane construction with fair alinement except for the southern section between control points 1 and 2 (see fig. 1). This southern section was essentially of two-lane construction with poor alinement. The test car encountered traffic congestion particularly on section 1–2; within the numerous small municipalities that lie on the route from control points 1 to 6; on the bypass around Camden in section 2–3; and on parts of the sections between control points 6 and 10 where the route passed through a highly urbanized area. The congestion was most severe from control points 8 to 10, which extend from the eastern approach of the Pulaski Skyway to the George Washington Bridge.

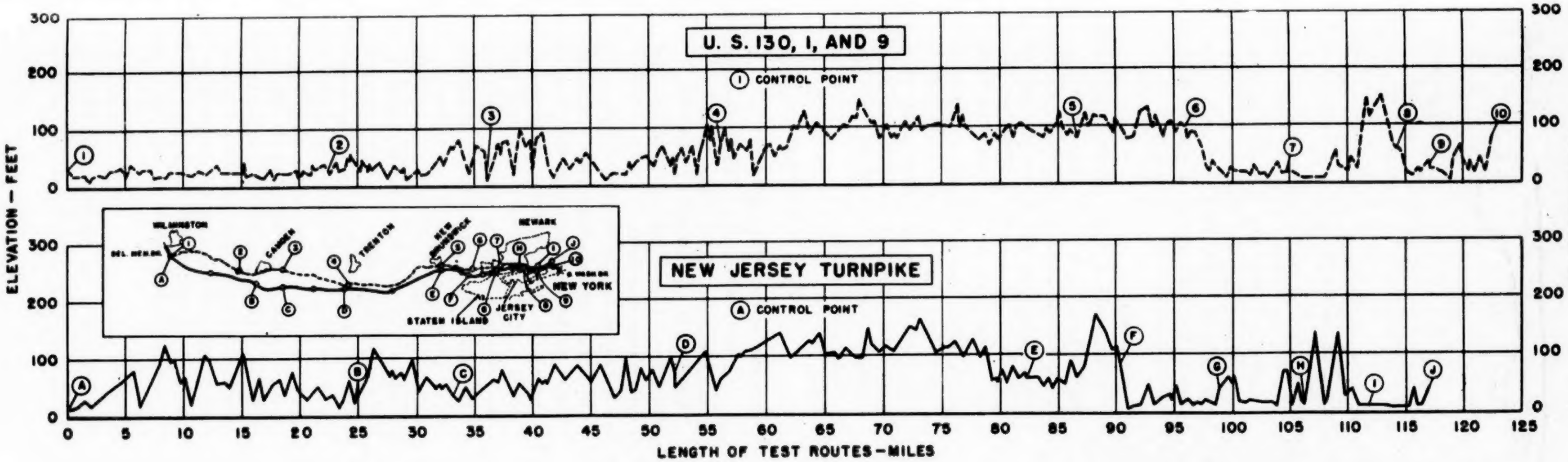



*Figure 1.—Profile and sketch of New Jersey Turnpike and U. S. 130, 1, and 9 between the Delaware Memorial Bridge and the George Washington Bridge.*

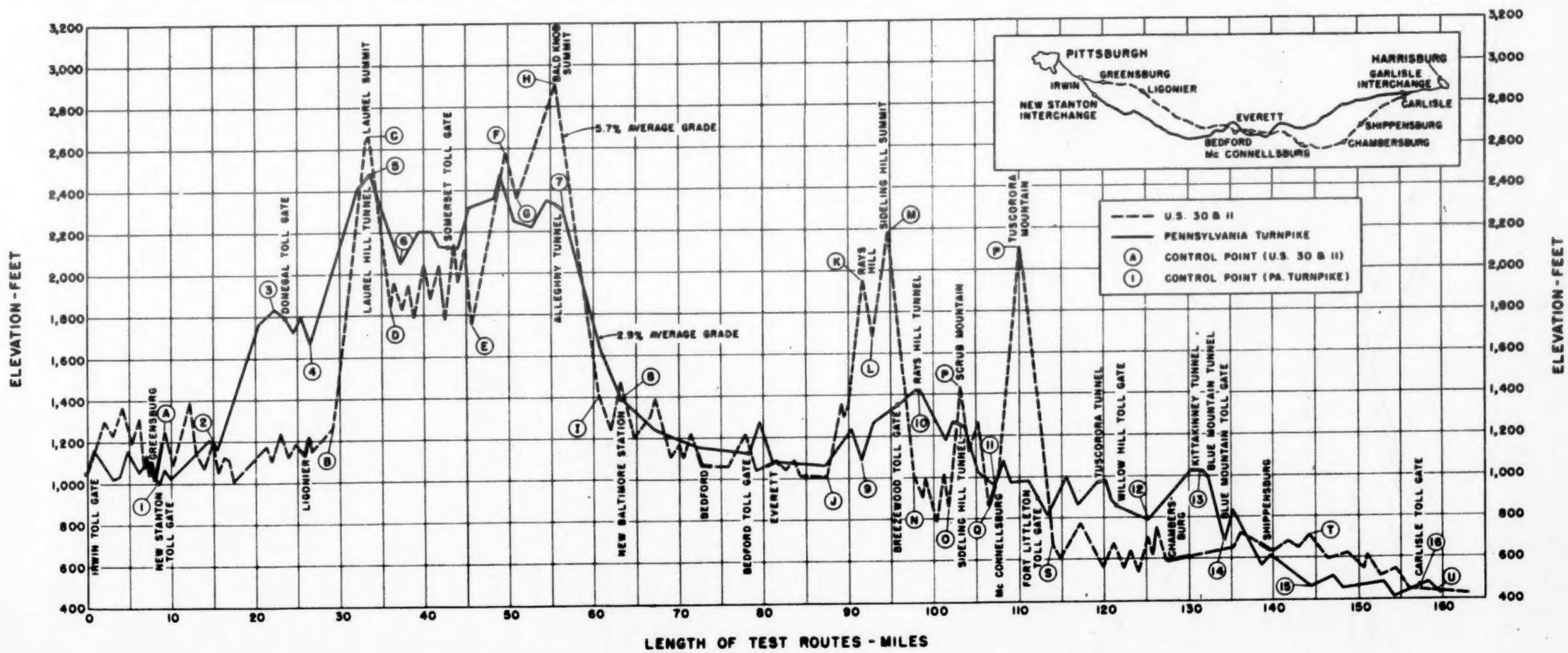



*Figure 2.—Profile and sketch of the Pennsylvania Turnpike and U. S. 30 and 11 between Carlisle and Irwin interchanges.*

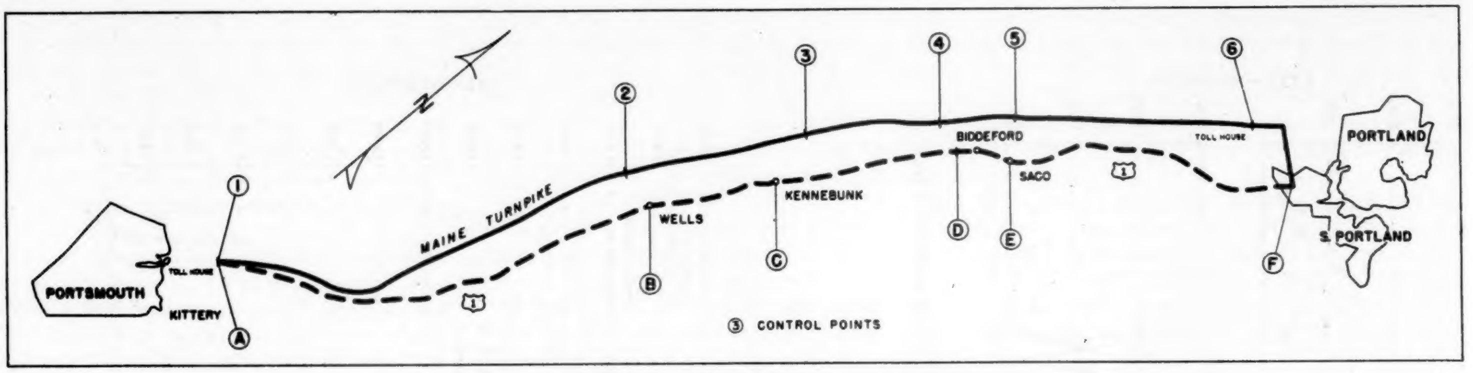



*Figure 3.—Sketch of the Maine Turnpike and U. S. 1.*

In Maine, the parallel route was a two-lane highway with rather poor alinement except for a short section near Portland. The test car was frequently slowed by passage through municipalities varying in population from a few hundred to over 20,000.

The route paralleling the middle section of the Pennsylvania Turnpike generally consisted of two lanes varying in individual width from 9 to 12 feet. Only a small mileage had lanes wider than 10 feet. Narrow shoulders, sharp curves, and restricted sight distances were the rule. The greater portion of the route had a bituminous surface with high crown prevailing in many sections. The operation over this route may be classed as strictly rural, since there are only six towns of any size, the largest of which was about 17,000 population. Traffic congestion was only a minor factor in the test runs on this route. The important factors with respect to passenger car operations were gradient and poor alinement.

The western portion of the Pennsylvania Turnpike bypasses Wilkinsburg, Pittsburgh, and an almost continuous string of municipalities which dot the north bank of the Ohio River between Pittsburgh and Rochester. The parallel major highway was principally urban for about 70 percent of its length.

In Virginia, U. S. 1 parallels the Shirley Memorial Highway and passes through Alexandria and its environs which constitute over 30 percent of the test route. Restricted speed zones also exist through areas of heavy roadside development and through a military reservation. Actually more than 50 percent of the route is zoned for a maximum speed of 35 miles per hour or less. This route in the rural areas is a four-lane highway with fair alinement.

**Special studies**

One of the four special studies was made to supplement data previously obtained by tests of vehicle performance on an old road and subsequently on a complete relocation of improved alinement between a junction near Frederick and the city limits of Hagerstown, Md. The sketch and profiles of the two test routes are shown in figure 6. In length and rise and fall, there is little to choose between the two locations. The rates of rise and fall were 3.7 for the new road and 4.1 for the old road, the highest rates of all the test routes. Moreover, on each road grades range as steep as 8 percent, and on each, heavy grades run a mile or more in length. The big difference between the two roads lies in the percentage of the total lengths that permit passing. On the old road 49.3 percent in one direction and 45.6 percent in the other, or nearly half of the total length, was marked for no passing. On the new road only 12.2 percent of the length in one direction and 11.6 percent in the other would not permit safe passing.

Another special study involved two possible routes between two bridges across the Potomac River at Washington, D. C., and Annandale, Va. (see fig. 7). This study was made primarily to obtain average running times of passenger cars for use in a study of the effect of travel time and distance on freeway usage.[1] However, while the running times were being observed the other vehicle characteristics were also studied. The first leg of each route was identical, being a rather low-speed freeway operation (posted limit of 40 miles per hour) on the Pentagon network. One of the routes followed Columbia Pike to Annandale, on which there were numerous intersections at grade, and on which there was heavy traffic congestion during the morning and evening peaks. The other route, included a section of the Shirley Memorial Highway and Virginia State Route 236. About two-thirds of the latter route was a freeway as compared to about one-fourth of the route to Annandale by way of Columbia Pike.

A third study was made for the Regional Highway Planning Committee for Metropolitan Washington to aid in determining the need for constructing an interchange ramp at 14th Street, SW., and Maine Avenue in Washington, D. C., which would eliminate an at-grade intersection for traffic desiring to make a left turn from Maine Avenue into 14th Street. A grade separation had been built at this location, but the one intersection leg was retained at grade because the ramp had to pass through a corner of the Bureau of Engraving and Printing Building. Only travel time and fuel consumption were measured on this study during both the peak and off-peak traffic periods.

The fourth special study was made on a 2-mile section of Columbia Pike between 4-Mile Run Drive and Scott Street as indicated in figure 7. Tests were made during peak and off-peak periods when there were 2 traffic light installations, and then repeated when 11 additional traffic-actuated signals had been installed within the same section.

**Special tests**

In addition to the freeway and special studies that have just been described, tests were made to determine the fuel consumption and accelerating ability of the test car on individual grades of 0.0, 2.84, 6.0, and 8.0 percent. The grades were 1.00, 0.40, 0.284 and 0.50 miles in length, respectively. All of these grades were at elevations of 900 feet or less, and all except the 8.0-percent grade were surfaced with portland cement concrete. The 8-percent grade was paved with a high-type bituminous concrete.

## Test Procedure

**Freeway and special studies**

The instruments installed in the test car were described in detail in a previous report.[2] For that reason, this report will consider only the type of information collected and the procedures employed.

A typical field data sheet is shown in figure 8 for the southernmost section of the major highway paralleling the New Jersey Turnpike. The recording apparatus consisted of five banks of 10 counters each, an electric clock, and a master time counter. These counters were actually arranged in the same pattern as the field data sheet. Each count represented one second on the banks of counters for speed, braking, engine torque, and throttle opening; and one-thousandth of a gallon on the bank of counters for gasoline consumption. Each counter of a bank represented a class interval of the particular item being studied. The units of the class intervals were miles per hour for speed and gasoline consumption, feet per second per second for braking, and percent for engine torque and throttle opening. The range in the class intervals for each bank of counters is shown in figure 8.

The time read from the electric clock was used to check the proper functioning of the master counter, and in turn, the time indi-

[1] *The effect of travel time and distance on freeway usage*, by Darel L. Trueblood. PUBLIC ROADS, vol. 26, No. 12, Feb. 1952.

[2] *A study of vehicle, roadway, and traffic relationships by means of statistical instruments* by Thomas J. Carmichael and Charles E. Haley. Proceedings of the Highway Research Board, vol. 30, 1950, pp. 282–296.

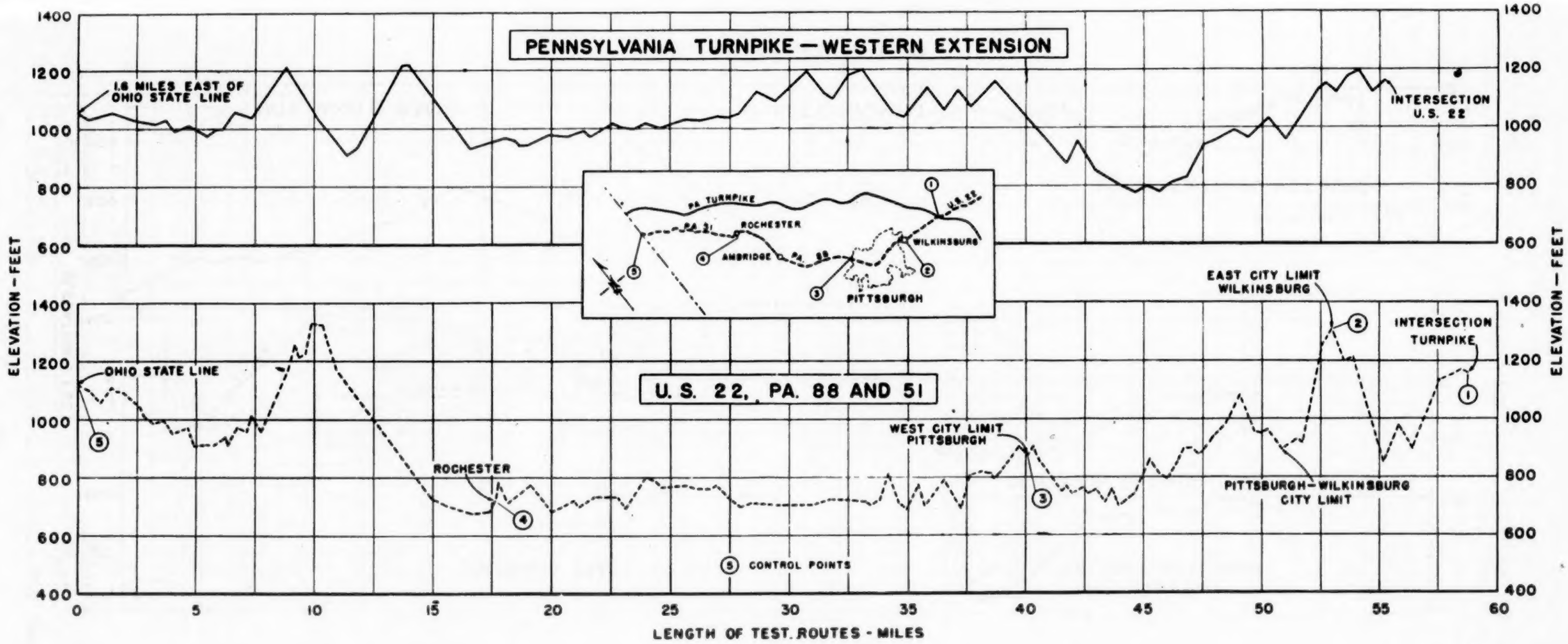



*Figure 4.—Profile and sketch of the western extension of the Pennsylvania Turnpike and U. S. 22, Pa. routes 88 and 51 between the Ohio-Pennsylvania line and junction of U. S. 22 and the Turnpike east of Pittsburgh.*

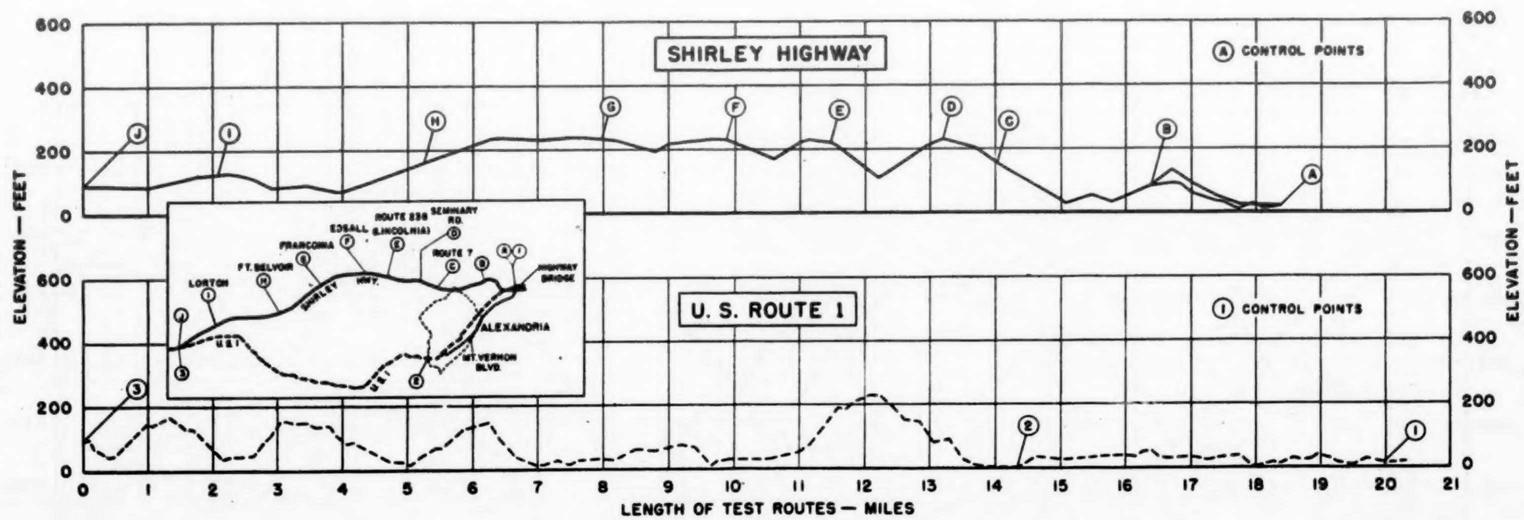



*Figure 5.—Profile and sketch of the Shirley Memorial Highway and U. S. 1 between Highway Bridge and junction near Woodbridge, Va.*

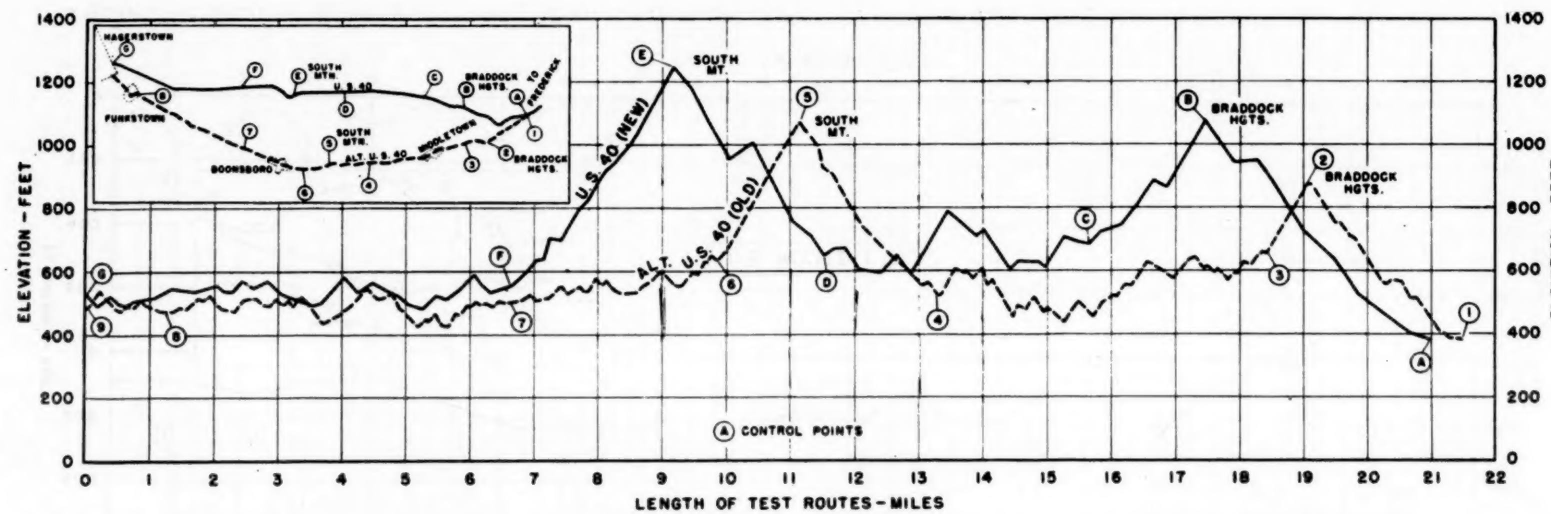



*Figure 6.—Profile and sketch of U. S. 40 and alternate U. S. 40 between Hagerstown and junction near Frederick, Md.*

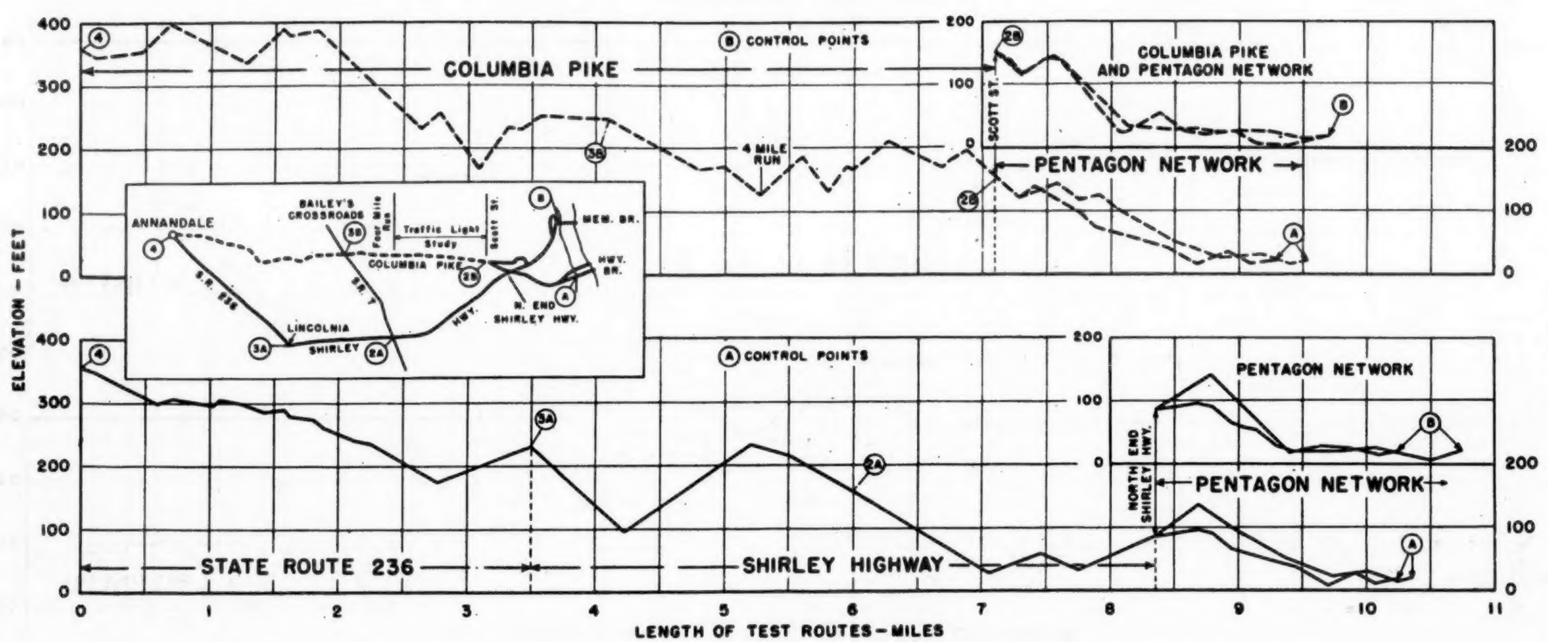



*Figure 7.—Profile and sketch of test routes between Annandale, Va., and Highway and Memorial Bridges, Washington, D. C.*

cated by the master counter was used to ascertain that all counters of a given bank were functioning properly. It is seen that the total time counts shown opposite the counter banks checked very closely with the master time counter. Likewise, the trip time from the electric clock compares closely with that of the master counter. As indicated in figure 8, the end results were an average rate of speed and gasoline consumption, percentage of time spent in each range of speed, deceleration, percentage of maximum torque and full throttle opening, and percentage of gasoline used in the various speed ranges. The time recorded on the master time counter was used to compute the average speed.

Engine torque was not directly recorded, instead it was assumed to be proportional to the pressure existing in the intake manifold. The intake manifold vacuum instrument consisted of a metal bellows to which was attached a calibrated spring and a swing arm that passed over a sector divided into contact segments representing ranges in vacuum. These ranges in vacuum were assigned engine torque values in percentage of maximum torque, as shown in figure 8. The maximum torque referred to in this instance roughly approximates the maximum for the engine speed or corresponding road speed at the instant of recording. It is not to be confused with the peak engine torque. The percentage values can be converted roughly to pound-feet of torque or pounds of tractive effort by assuming an average maximum torque for the entire range of engine speed involved.

The average test method was used when the traffic volume was dense enough for the

**Test No.** B-Run 2 **Date** October 23, 1951

**Route** U. S. 130, 1 and 9, Major highway parallel to New Jersey Turnpike

**Remarks** Section 1 - 2, Northbound

Deepwater to Thorofare, U. S. 130 before opening of Turnpike

**SPEED**

| Counter No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total counts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed, MPH | 0-5 | 6-8 | 9-11 | 12-18 | 19-23 | 24-35 | 36-46 | 47-56 | 57-68 | 69 & up | |
| Finish | 36349 | 43778 | 22724 | 57671 | 63082 | 36613 | 32259 | 18835 | 46931 | 07078 | |
| Start | 36335 | 43777 | 22720 | 57650 | 63031 | 35894 | 31306 | 18487 | 46931 | 07078 | |
| Difference | 14 | 1 | 4 | 21 | 51 | 719 | 952 | 348 | 0 | 0 | 2110 |
| % Total | 0.7 | 1/ | 0.2 | 1.0 | 2.4 | 34.1 | 45.1 | 16.5 | 0 | 0 | |

**GASOLINE CONSUMPTION**

| Counter No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total counts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed, MPH | 0-5 | 6-8 | 9-11 | 12-18 | 19-23 | 24-35 | 36-46 | 47-56 | 57-68 | 69 & up | |
| Finish | 33046 | 49290 | 59817 | 92727 | 60401 | 40136 | 99300 | 00050 | 51920 | 03729 | |
| Start | 33045 | 49290 | 59816 | 92723 | 60384 | 39833 | 98752 | 99769 | 51920 | 03729 | |
| Difference | 1 | 0 | 1 | 4 | 17 | 303 | 548 | 281 | 0 | 0 | 1155 |
| % Total | 0.1 | 0 | 0.1 | 0.3 | 1.5 | 26.2 | 47.5 | 24.3 | 0 | 0 | |

**BRAKING**

| Counter No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total counts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Deceleration | 0-3 | 4-7 | 8-10 | 11-13 | 14-16 | 17-19 | 20-23 | 24-26 | 27-29 | 30 & up | |
| Finish | 74418 | 29629 | 06203 | 02380 | 02206 | 02542 | 02141 | 06856 | 85677 | 03158 | |
| Start | 72309 | 29614 | 06203 | 02380 | 02206 | 02542 | 02141 | 06856 | 85677 | 03158 | |
| Difference | 2109 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2124 |
| % Total | 99.3 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

**ENGINE TORQUE**

| Counter No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total counts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % Torque | Coast | 0-10 | 11-21 | 22-32 | 33-43 | 44-55 | 56-66 | 67-77 | 78-88 | 89-100 | |
| Finish | 77642 | 79928 | 19508 | 14947 | 27422 | 41757 | 25848 | 21789 | 43770 | 08527 | |
| Start | 77588 | 79679 | 19103 | 14367 | 26790 | 41630 | 25776 | 21741 | 43751 | 08526 | |
| Difference | 54 | 249 | 405 | 580 | 632 | 127 | 72 | 48 | 19 | 1 | 2187 |
| % Total | 2.5 | 11.4 | 18.5 | 26.5 | 28.9 | 5.8 | 3.3 | 2.2 | 0.9 | 1/ | |

**THROTTLE OPENING**

| Counter No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total counts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % Opening | 0-9 | 10-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 80-89 | 90-100 | |
| Finish | 44203 | 84569 | 82488 | 98040 | 41216 | 31988 | 26359 | 23185 | 29305 | 46465 | |
| Start | 44164 | 83742 | 81669 | 97610 | 41189 | 31988 | 26359 | 23185 | 29305 | 46465 | |
| Difference | 39 | 827 | 819 | 430 | 27 | 0 | 0 | 0 | 0 | 0 | 2142 |
| % Total | 1.8 | 38.6 | 38.2 | 20.1 | 1.3 | 0 | 0 | 0 | 0 | 0 | |

**ODOMETER**

| | | |
|---|---|---|
| Finish | 8367.45 | |
| Start | 8345.20 | |
| Trip Mileage | | 22.25 |

**CLOCK**

| | | |
|---|---|---|
| Finish | 5:52 P.M. | |
| Start | 5:17 P.M. | |
| Trip Time (Seconds) | | 2100 |

**MASTER COUNTER**

| | | |
|---|---|---|
| Finish | 15014 | |
| Start | 12891 | |
| Total Counts (Seconds) | | 2123 |

**Trip Average Speed** 37.7 **MPH** **Trip Average Gas Consumption** 19.3 **MPG**

1/ Less than 0.05%

*Figure 8.—A typical field data sheet used in recording information on vehicle operating characteristics.*

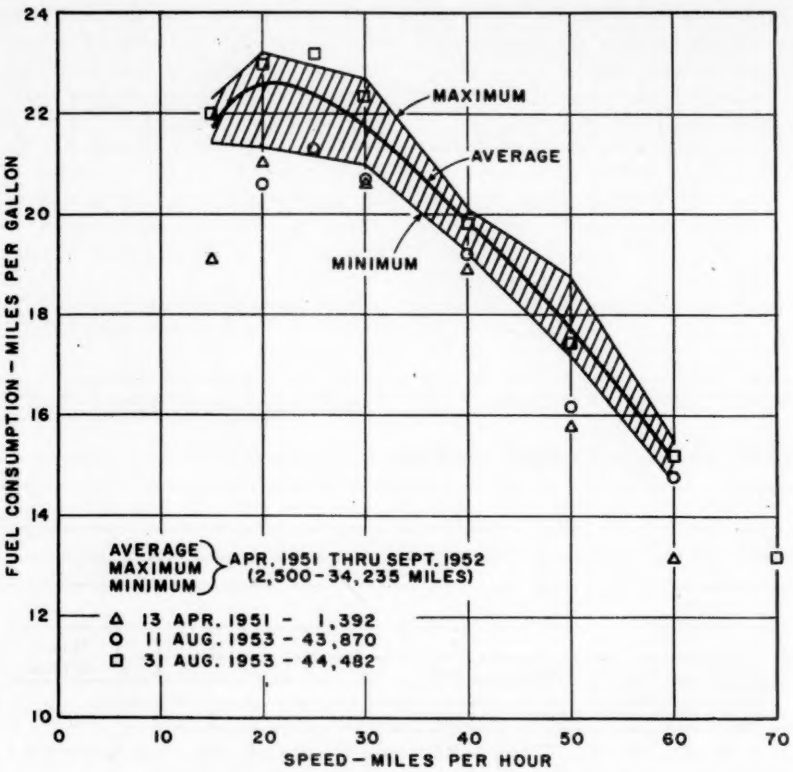



*Figure 9.—Fuel calibration of test car in third gear with burette on a 1-mile level section for various sustained speeds.*

driver to reliably approximate the speed of all traffic at a given instant. Where the average test method was not feasible, test runs were made on a particular section at three or more attempted speeds so that the rate of fuel consumption could be interpolated for an average overall travel speed of all passenger cars obtained from other sources. Attempted speeds greater than 60 miles per hour were not possible, because the fuelmeter did not have sufficient volume to supply the flow of fuel required to negotiate existing grades at higher speeds.

Three test runs were made over each test route in each direction at each attempted speed for all except two of the studies. For the intersection study at Maine Avenue and 14th Street, Washington, D. C., 12 test runs were made in the off-peak period and 26 test runs in the peak period. For the traffic light study on Columbia Pike (see fig. 7), 4 and 16 test runs were made before the installation of additional traffic lights during the off-peak and peak periods, respectively. After the installation, 6 and 18 test runs were made during the off-peak and peak periods, respectively. The test runs were scheduled so that a particular test section or route would be traveled at different times during the period of study.

**Fuel calibration**

In order to maintain the fuel characteristics of the test car at approximately the same level throughout the period of the study, calibration tests were conducted before and after most of the studies. The fuel consumption of the test car was checked with a burette on a measured mile located on the Shirley

**Table 1.—Horsepower and torque data of test car [1]**

| Road speed in third gear | Maximum gross horsepower | Maximum gross torque |
|---|---|---|
| *M. p. h.* | | *Lb./ft.* |
| 20 | 34 | 185 |
| 25 | 44 | 191 |
| 30 | 54 | 191 |
| 35 | 63 | 189 |
| 40 | 72 | 186 |
| 50 | 85 | 178 |
| 60 | 94 | 163 |
| 70 | 96 | 143 |
| 80 | 91 | 119 |

[1] Taken from curves in Manufacturer's Shop Manual.

Memorial Highway. Test runs were made in both directions over the section at speeds of 15, 20, 25, 30, 40, 50, and 60 miles per hour.

The results of 13 such calibration tests are shown in figure 9. The average consumption rates in miles per gallon, between April 1951 and September 1952 when the odometer readings ranged from 2,500 to 34,235 miles, are shown by the smooth curve. The variation in rates of consumption from the average during this period is indicated by the maximum and minimum values, each of which is connected by a series of straight lines. The percentage of variation from the average ranged from 1.4 to 6.2 percent. In view of this rather small variation, which was

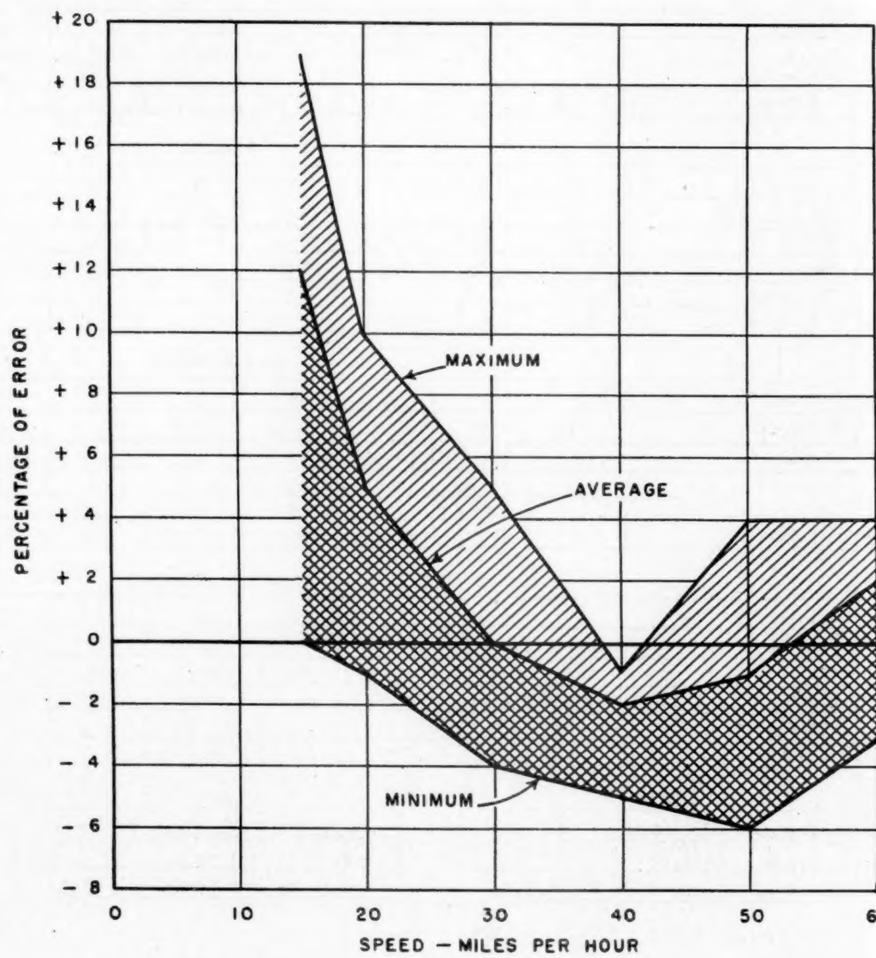



*Figure 10.—Calibration of fuelmeter with a burette on a 1-mile level section for various sustained speeds during period, Apr. 1951–52.*

## Table 2.—Summary of average composite performance of test vehicle on various routes

| Type of facility[1] | Test route | Date of tests | Period of study[2] | Length of route | Rise and fall | Speed: Attempted | Speed: Average | Fuel consumption (corrected) | Braking: Percent time 0-3 ft./sec.[2] | Braking: Percent time Over 3 ft./sec.[2] | Braking: Maximum deceleration | Braking: Time factor | Average engine torque | Average throttle opening |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Miles* | *Ft./100 ft.* | *M. p. h.* | *M. p. h.* | *M. p. g.* | *Percent* | *Percent* | *Ft./sec.*[2] | *Sec./100 mi.* | *Percent* | *Percent* |
| 1A Freeway | Delaware Memorial Bridge to George Washington Bridge via New Jersey Turnpike. | Apr. 1952 | 8 a. m.–6 p. m. | 116.3 | 0.8 | 40 | 39.4 | 18.6 | 100.0 | ([3]) | 8–10 | 2.6 | 29.0 | 17.1 |
| | | | | | | 50 | 48.6 | 17.2 | 100.0 | ([3]) | 8–10 | 2.4 | 33.8 | 21.1 |
| | | | | | | 60 | 58.1 | 15.4 | 99.9 | 0.1 | 11–13 | 5.3 | 45.4 | 34.1 |
| 1B Major highway. | Delaware Memorial Bridge to George Washington Bridge via U. S. 130, 1, and 9. | Oct. 1951 | do | 122.2 | .9 | ([4]) | 38.3 | 17.4 | 98.1 | 1.9 | 14–16 | 181.2 | 31.4 | 25.7 |
| | | Apr. 1952 | do | ----- | ---- | ([4]) | 40.7 | 17.2 | 98.2 | 1.8 | 14–16 | 159.0 | 34.8 | 20.3 |
| 2A Freeway | Carlisle interchange to New Stanton interchange via Pennsylvania Turnpike. | ([5]) | do | 148.7 | 1.4 | 40 | 40.2 | 18.8 | 100.0 | ([3]) | 11–13 | 2.7 | 27.0 | 14.7 |
| | | ([5]) | do | ----- | ---- | 50 | 49.0 | 16.8 | 99.9 | .1 | 8–10 | 7.6 | 33.5 | 17.8 |
| | | June 1952 | do | ----- | ---- | 60 | 57.1 | 15.1 | 99.7 | .3 | 11–13 | 18.5 | 42.6 | 31.3 |
| 2B Major highway. | Carlisle to Greensburg, Pa., via U. S. 11 and 30 (including larger towns). | do | do | 149.4 | 3.3 | 30 | 30.6 | 17.6 | 99.4 | .6 | 11–13 | 70.5 | 30.2 | ----- |
| | | | | | | 40 | 38.0 | 16.6 | 99.0 | 1.0 | 11–13 | 93.5 | 32.6 | ----- |
| | | | | | | 50 | 42.7 | 15.6 | 97.6 | 2.4 | 14–16 | 196.8 | 36.3 | ----- |
| 2C Major highway. | Carlisle to Greensburg, Pa., via U. S. 11 and 30 (excluding larger towns). | do | do | 140.3 | 3.4 | 30 | 31.6 | 17.5 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 40 | 40.3 | 16.5 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 50 | 46.0 | 15.5 | ---- | ---- | ---- | ---- | ----- | ----- |
| 3A Freeway | Kittery to Portland, Maine, via Maine Turnpike. | Aug. 1952 | do | 41.8 | 1.2 | 40 | 39.8 | 19.3 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 50 | 49.0 | 16.5 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 60 | 58.8 | 14.9 | ---- | ---- | ---- | ---- | ----- | ----- |
| 3B Major highway. | Kittery to Portland, Maine, via U. S. 1. | do | Weekday | 43.8 | 1.3 | ([4]) | 36.4 | 17.9 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | Weekend | ----- | ---- | ([4]) | 35.1 | 17.7 | ---- | ---- | ---- | ---- | ----- | ----- |
| 4A Freeway | Pittsburgh interchange to Ohio State line via Pennsylvania Turnpike. | July 1952 | 8 a. m.–6 p. m. | 55.2 | 1.4 | 40 | 40.3 | 19.0 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 50 | 49.8 | 17.4 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 60 | 58.8 | 15.7 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | Oct. 1952 | do | ----- | ---- | 40 | 39.9 | 19.1 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 50 | 49.9 | 17.1 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | | | | | 60 | 58.8 | 15.6 | ---- | ---- | ---- | ---- | ----- | ----- |
| 4B Major highway. | Pittsburgh interchange to Ohio State line via U. S. 22, Pa. 19 (alternate), 88, and 51 (through Pittsburgh). | Dec. 1951 | do | 58.5 | 2.0 | ([4]) | 26.4 | 16.7 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | [6] (17.6) | 1.9 | ([4]) | 35.8 | 18.2 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | [7] (40.9) | 2.1 | ([4]) | 23.8 | 16.2 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | July 1952 | do | [7] 40.9 | 2.1 | ([4]) | 25.9 | 16.7 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | Oct. 1952 | do | [7] 40.9 | 2.1 | ([4]) | 25.1 | 16.6 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | July 1952 | do | [8] 12.9 | 2.7 | ([4]) | 18.3 | 14.9 | ---- | ---- | ---- | ---- | ----- | ----- |
| 5A Freeway | Washington, D. C., (Highway Bridge) to Woodbridge, Va., via Shirley Memorial Highway. | Dec. 1951 | Off-peak | [9] 18.4 | 1.3 | ([4]) | 49.8 | 17.9 | 99.7 | .3 | 8–10 | 19.7 | 38.8 | 24.7 |
| | | Mar. 1954 | do | ----- | ---- | ([4]) | 50.9 | 17.2 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | 14.1 | 1.1 | 30 | 30.8 | 21.1 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | ----- | ---- | 40 | 40.6 | 19.6 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | ----- | ---- | 50 | 49.5 | 17.9 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | do | ----- | ---- | 55 | 53.2 | 16.8 | ---- | ---- | ---- | ---- | ----- | ----- |
| 5B Major highway. | Washington, D. C., (Highway Bridge) to Woodbridge, Va., via U. S. 1. | Dec. 1951 | do | 20.3 | 1.7 | ([4]) | 33.8 | 18.9 | 98.9 | 1.1 | 11–13 | 120.7 | 31.0 | 17.7 |
| | | do | do | [10](6.0) | 1.0 | ([4]) | 23.6 | 18.1 | 97.9 | 2.1 | 11–13 | 318.8 | 28.7 | 12.4 |
| | | do | do | [6](14.3) | 1.9 | ([4]) | 40.7 | 19.2 | 99.5 | .5 | 8–10 | 43.4 | 32.7 | 21.2 |
| 5C Major highway. | Washington, D. C., (Highway Bridge) to Woodbridge, Va., via Mount Vernon Blvd. and U. S. 1. | do | do | 20.4 | 1.7 | ([4]) | 36.4 | 18.8 | 98.7 | 1.3 | 11–13 | 127.0 | 31.8 | 20.6 |
| | | do | do | [10](6.1) | 1.0 | ([4]) | 28.8 | 17.7 | 97.3 | 2.7 | 11–13 | 335.8 | 30.3 | 17.1 |
| | | do | do | [6](14.3) | 1.9 | ([4]) | 40.7 | 19.2 | 99.5 | .5 | 8–10 | 43.4 | 32.7 | 21.2 |
| 6A Major highway. | Frederick to Hagerstown, Md., via new U. S. 40. | July 1951 | 8 a. m.–6 p. m. | 21.0 | 3.7 | 30 | 32.3 | 18.5 | 100.0 | ([3]) | 4–7 | 1.2 | 26.8 | 23.1 |
| | | do | do | ----- | ---- | 40 | 40.9 | 17.5 | 100.0 | 0 | 0–3 | 0 | 30.3 | 26.2 |
| | | Sept. 1952 | do | ----- | ---- | 40 | 39.6 | 17.5 | 99.1 | .1 | 4–7 | 7.2 | ----- | ----- |
| | | July 1951 | do | ----- | ---- | 50 | 49.4 | 16.2 | 99.7 | .3 | 27–29 | 22.8 | 34.2 | 29.4 |
| | | Aug. 1952 | do | ----- | ---- | 50 | 48.5 | 15.8 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | Sept. 1952 | do | ----- | ---- | 50 | 47.7 | 16.0 | 99.7 | .3 | 8–10 | 21.6 | ----- | ----- |
| | | July 1951 | do | ----- | ---- | 60 | 53.4 | 14.8 | 99.6 | .4 | 8–10 | 28.7 | 41.0 | 33.9 |
| | | Sept. 1952 | do | ----- | ---- | 60 | 54.6 | 14.6 | 98.8 | 1.2 | 8–10 | 79.1 | ----- | ----- |
| 6B Major highway. | Frederick to Hagerstown, Md., via old U. S. 40. | July 1951 | do | 21.5 | 4.1 | ([11]) | 35.9 | 16.6 | 99.2 | .8 | 8–10 | 82.4 | 29.9 | 20.7 |
| 7A Freeway | Washington, D. C., (Highway Bridge) to Annandale, Va., via Shirley Memorial Highway. | do | Peak | 10.3 | 1.8 | ([4]) | 40.0 | 16.4 | 98.6 | 1.4 | 8–10 | 120.8 | 31.4 | 26.2 |
| | | do | Off-peak | ----- | ---- | ([4]) | 43.9 | 17.7 | 99.5 | .5 | 4–7 | 38.7 | 33.8 | 28.8 |
| 7B Major highway. | Washington, D. C., (Highway Bridge) to Annandale, Va., via Columbia Pike. | do | Peak | 9.4 | 2.4 | ([4]) | 26.6 | 15.4 | 97.5 | 2.5 | 8–10 | 315.3 | 29.3 | 20.1 |
| | | do | Off-peak | ----- | ---- | ([4]) | 33.1 | 17.8 | 98.2 | 1.8 | 8–10 | 219.1 | 28.5 | 20.4 |
| 7C Freeway | Washington, D. C. (Memorial Bridge), to Annandale, Va., via Shirley Memorial Highway | do | Peak | 10.5 | 1.8 | ([4]) | 41.0 | 16.4 | 99.7 | .3 | 4–7 | 28.5 | 29.9 | 26.2 |
| | | do | Off-peak | ----- | ---- | ([4]) | 45.3 | 17.7 | 98.6 | 1.4 | 8–10 | 114.0 | 35.1 | 29.6 |
| 7D Major highway. | Washington, D. C., (Memorial Bridge) to Annandale, Va., via Columbia Pike | do | Peak | 9.7 | 2.4 | ([4]) | 26.5 | 15.4 | 97.3 | 2.7 | 11–13 | 366.9 | 30.0 | 19.5 |
| | | do | Off-peak | ----- | ---- | ([4]) | 34.3 | 17.4 | 98.6 | 1.4 | 11–13 | 149.9 | 29.1 | 22.5 |
| 8 Major street | Washington, D. C., (1301 Maine Ave.) to Inlet Bridge | Oct. 1951 | Peak | 0.23 | 0.2 | ([4]) | 8.9 | 9.6 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | Off-peak | ----- | ---- | ([4]) | 18.4 | 13.1 | ---- | ---- | ---- | ---- | ----- | ----- |
| 9 Major highway | Arlington, Va., (Columbia Pike from 4-mile Run Drive to Washington Blvd. underpass) | Apr. 1952 | Peak | 2.00 | 3.1 | ([4]) | 21.4 | 13.3 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | Off-peak | ----- | ---- | ([4]) | 26.1 | 16.3 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | Aug. 1952 | Peak | ----- | ---- | ([4]) | 21.5 | 14.2 | ---- | ---- | ---- | ---- | ----- | ----- |
| | | do | Off-peak | ----- | ---- | ([4]) | 24.9 | 14.6 | ---- | ---- | ---- | ---- | ----- | ----- |

[1] For comparison, facilities are numbered to indicate freeways and major parallel highways.
[2] A minimum of 3 round trips was made over each test route spaced to cover the period indicated.
[3] Less than 0.05 percent.
[4] Average test method used.
[5] 1 test run in December 1951 and 2 test runs in June 1952.
[6] Rural traffic conditions.
[7] Urban traffic conditions.
[8] Through Wilkinsburg and Pittsburgh, Pa.
[9] Speed limit posted at 40 m. p. h. for 1.9 miles, 50 m. p. h. for 2.4 miles, and 55 m. p. h. for 14.1 miles.
[10] Through Alexandria, Va.
[11] Attempted to drive average speed (33.6 m. p. h.) for passenger cars observed before opening of new U. S. 40.



348404—55——2

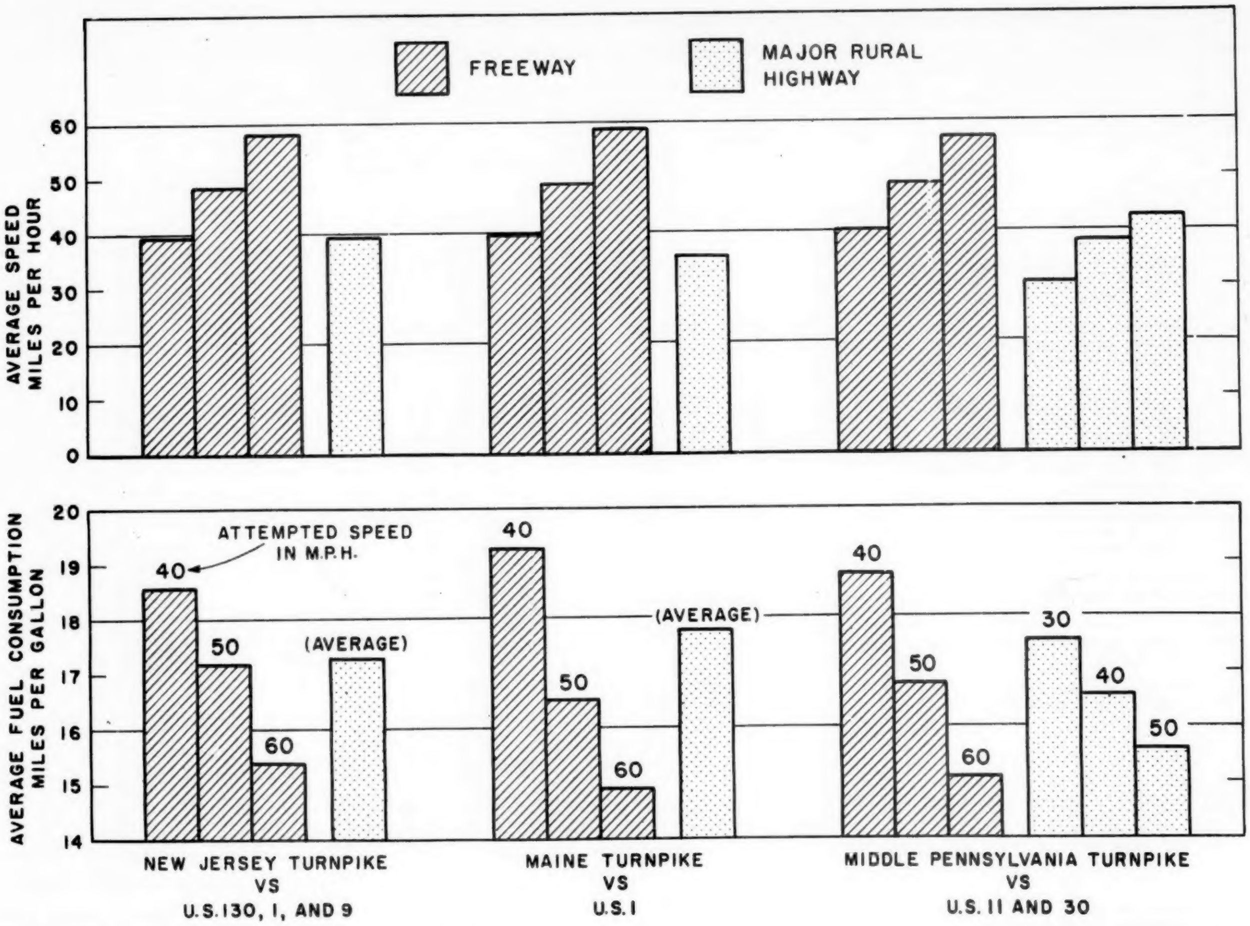



*Figure 11.—Fuel consumption and speed of test car on freeways compared with that on parallel major rural highways.*

obtained by frequent engine tune-ups, no attempt was made to correct the results for changing fuel-consumption characteristics. The triangular shaped points are the rates of consumption observed before the start of the project when there were 1,392 miles on the odometer and the engine was apparently either not properly "broken-in" or tuned.

In the fall of 1953, about one year after the completion of the freeway and special studies, it was planned to make some special grade tests with the same passenger car. The vehicle was calibrated at that time, and the rates of consumption, indicated by the circular points in figure 9, were found to be less than the minimum rates observed for the previous period of tests. For this reason, the engine was given a tune-up that included the replacement of spark plugs, and overhaul of carburetor and distributor. The rates of consumption observed after this tune-up, indicated in figure 9 by the square-shaped symbols, fell generally on or above the average curve and well within the band created by the maximum and minimum lines.

**Calibration of instruments**

The accuracy of the instruments for measuring deceleration, throttle opening, and intake manifold vacuum was checked only a few

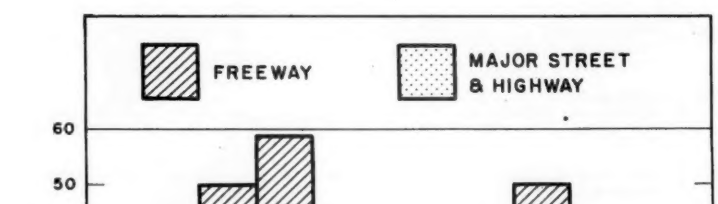



***Figure 12* (Right).—*Fuel consumption and speed on freeways compared with that on parallel major streets and highways. A sizable percentage of the latter mileage is in urban areas.***

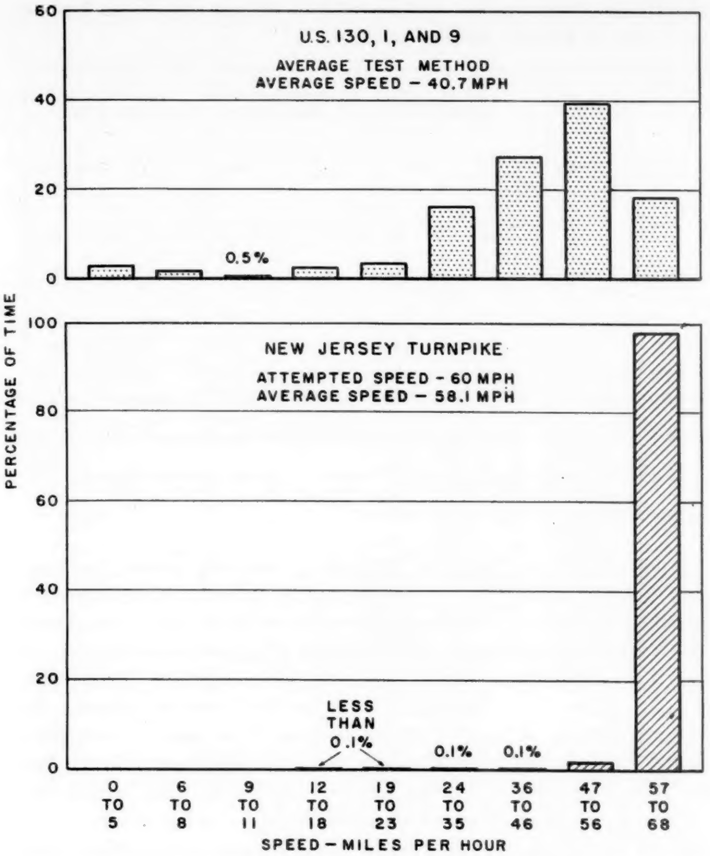



*Figure 13.—Time distribution by speed groups for the New Jersey Turnpike and parallel major highway.*

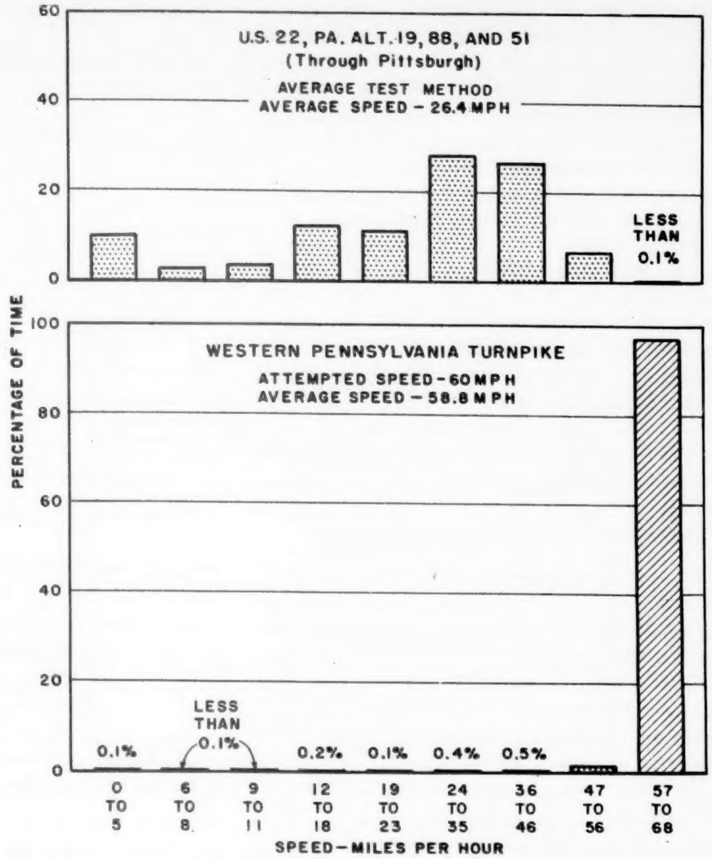



*Figure 14.—Time distribution by speed groups for the western Pennsylvania Turnpike and parallel major highway.*

times during the entire series of studies. However, the speedometer was calibrated frequently against the test car speedometer which in turn had been calibrated with an accurate speedometer actuated by a test wheel. It was found that the class intervals originally established for a given bank of counters did not vary appreciably during the tests.

The volumetric fuelmeter, which was of the positive displacement type, was calibrated in conjunction with the fuel calibration of the test vehicle before and after most of the studies. The results of the calibration tests, made with a burette that could be read to the nearest cubic centimeter, are shown in figure 10. These tests were conducted on a one-mile level section of highway at the indicated speeds. A plus error indicates that the fuelmeter reading in gallons was less than the true consumption. Of course, the opposite was true for a negative error.

Since speed is proportional to the rate of flow, it is evident in figure 10 that the fuelmeter did not give the same accuracy for all rates of flow. The fuelmeter was purposely adjusted to give the higher degree of accuracy for flow rates comparable to those for sustained speeds of 30 miles per hour or more, because rates of flow in that range were normally required. The average error was decidedly on the plus side for the lower flow rates and slightly on the negative side for the higher flow rates; it increased at a fast rate as the flow decreased below the flow rates comparable to speeds of 30 miles per hour or less. The fuelmeter reading will result in a rate of consumption that is considerably lower than the true rate, if the engine operates at or near idle speed for an appreciable portion of the total running time.

The results of the calibration tests were

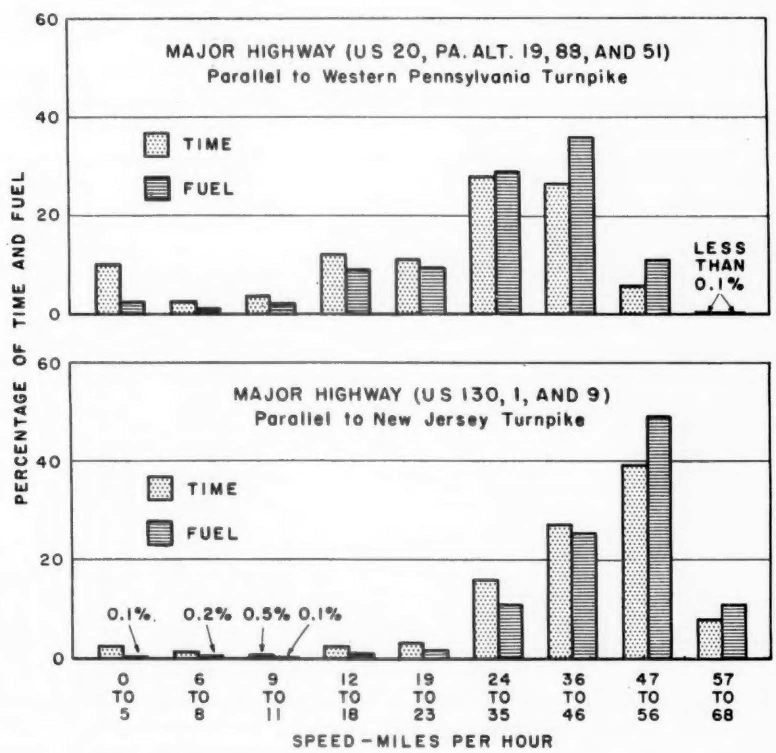



*Figure 15.—Comparison between time and fuel distribution, by speed groups, for major highways parallel to the New Jersey Turnpike and western Pennsylvania Turnpike.*

used to correct the observed rates of consumption to a common base, if it could be determined that the flow rates were consistently high. Correction factors could not be developed for those tests with considerable low-speed operation, since it was not possible from the speed record obtained on the counters to ascertain whether the vehicle was accelerating with a high flow rate or idling with a low flow rate. The variation in fuelmeter accuracy during a study was not of sufficient magnitude to affect materially the relative fuel consumption for two parallel routes studied at approximately the same time. However, it was necessary to correct to a common base in order to relate the results of the various studies, since the accuracy of the fuelmeter is shown in figure 10 to vary appreciably during the period of the studies.

**Table 3.—Comparison between fuel consumption and travel time of test vehicle on freeway and on parallel major highway**

| Test route | Length of route | | Average overall travel speed | | Average rate of fuel consumption | | Freeway-major highway ratio | |
|---|---|---|---|---|---|---|---|---|
| | Major highway | Freeway | Major highway [1] | Freeway [2] | Major highway | Freeway [3] | Travel time | Fuel consumption |
| | *Miles* | *Miles* | *M. p. h.* | *M. p. h.* | *M. p. g.* | *M. p. g.* | | |
| New Jersey Turnpike | 122.2 | 116.3 | 38.3 | 55 | 17.4 | 16.0 | 0.66 | 1.03 |
| Pennsylvania Turnpike, middle section | [4] 163.0 | [4] 159.7 | 42.7 | 57 | 15.6 | 15.1 | .73 | 1.01 |
| Maine Turnpike | 43.8 | 41.8 | 35.7 | 55 | 17.8 | 15.7 | .62 | 1.08 |
| Pennsylvania Turnpike, western extension | 58.5 | 55.2 | 26.4 | 57 | 16.7 | 16.0 | .44 | .99 |
| Shirley Memorial Highway, Va. | 20.3 | 18.4 | 33.8 | 50 | 18.9 | 17.9 | .61 | .96 |

[1] Results of using average test method, except for middle section of Pennsylvania Turnpike where attempted speed test method of 50 m. p. h. was used.
[2] Based on available reports of average overall travel speeds of passenger cars, except for Shirley Memorial Highway where average test method was used.
[3] Interpolated from results determined by attempted speed test method, except for Shirley Memorial Highway where average test method was used.
[4] Distance between Middlesex and Irwin interchanges.

### Special test procedures

In order to determine the relation between fuel consumption, speed, and degree of gradient, the test car was operated at sustained speeds ranging from 15 to 70 miles per hour on a 0.0-, 2.84-, 6.0- and 8.0-percent grade. For each sustained speed, at least three runs were made in both directions over a given grade. The fuel consumed by the test car was measured with a graduated burette which was connected in the fuel line between the car fuel pump and the carburetor. Fuel was pumped by the regular fuel pump into the burette and by an electric fuel pump from the burette to the carburetor. The temperature of the fuel in the burette was recorded for each run. Because the range of these temperatures was small, no attempt was made to correct the observed volumes to a standard base.

The accelerating ability of the test car was measured on the same four grades. Test runs were made with wide-open throttle in each direction on each test section, accelerating through each gear from a standing start to about 40 miles per hour, and in direct gear (third) from a speed of 20 miles per hour to the highest practicable speed. A minimum of two test runs was made for each condition of test.

The acceleration was determined from a record of time and distance, which was made on wax-coated paper fed through a chronograph at a constant speed of about 5 inches per second. Time was recorded on the tape at 1-second intervals by a small electrically actuated hammer wired to a timer. The record of distance was obtained by means of a rotating contact housed on a test wheel and driven by an odometer shaft. The rotating contact opened and closed an electrical circuit at every 2 feet of travel causing a stylus of the chronograph to make a crenelated trace on the moving tape.

A time-distance curve was plotted for each test run. This curve was differentiated by the mirror method at frequent points to determine instantaneous speeds. After the first differentiation, a time-speed curve was plotted and differentiated to obtain approximate instantaneous rates of acceleration. From these results, it was possible to derive relations for each grade that could be used to determine the distance and time required to accelerate between any two speeds, and the instantaneous acceleration rates for given speeds.

In conjunction with the acceleration tests, the fuel consumed while accelerating was measured with the burette at frequent points during each test run. When the burette was read, the chronograph tape was marked by pushing a switch wired to a stylus. It was then possible to determine the speed at the instant the burette was read. The result was an accumulative record of fuel consumption by speed which could be used to find the fuel consumed when accelerating between any two speeds.

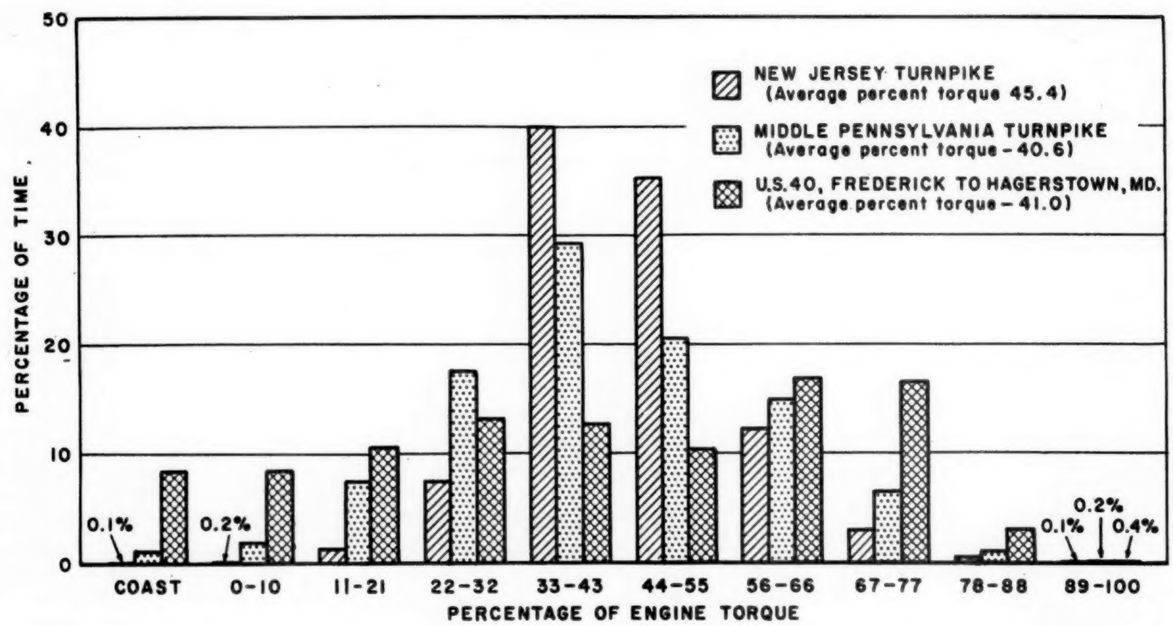



*Figure 16.—Comparison of time distribution by percentage of engine torque for attempted speed of 60 m. p. h. on three test routes with different profile characteristics.*

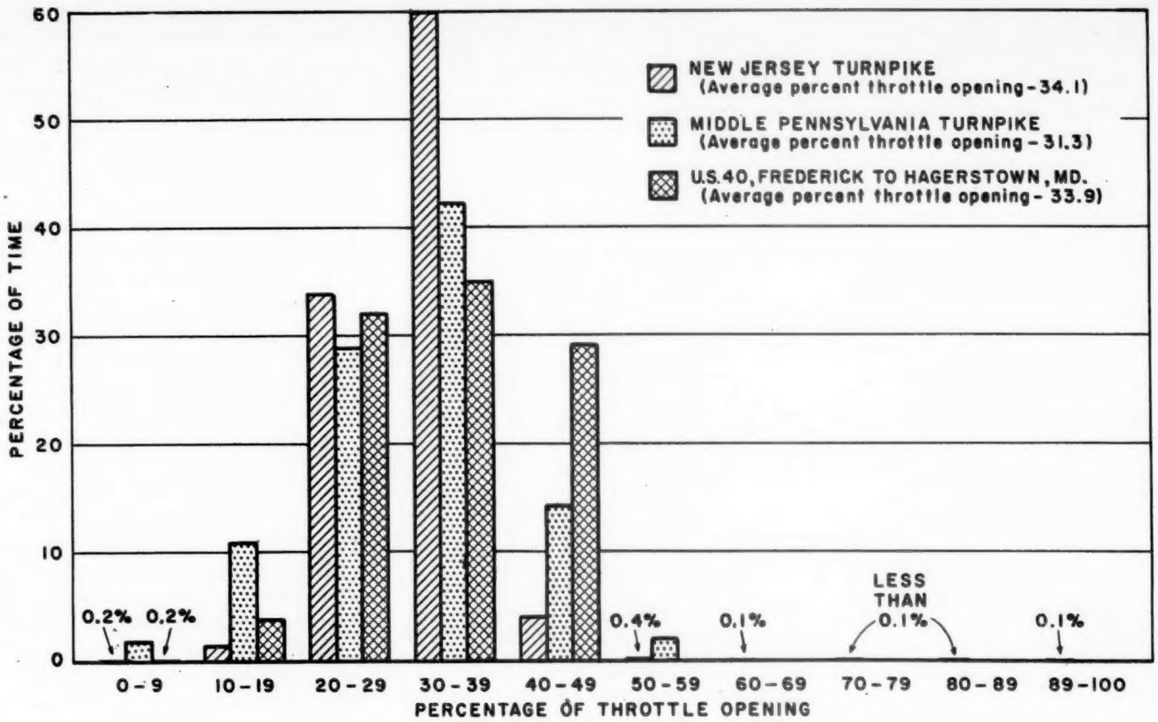



*Figure 17.—Comparison of time distribution by percentage of throttle opening for attempted speed of 60 m. p. h. on three test routes with different profile characteristics.*

The pertinent specifications of the test car are as follows:

| | |
|---|---|
| Make and model | 1951 Pontiac 6, 4-door sedan. |
| Transmission | 3-speed synchromesh. |
| Weight: | |
| Front | 1,920 pounds. |
| Rear | 2,080 pounds. |
| Total | 4,000 pounds. |
| Bore and stroke | 3-9/16 × 4 inches. |
| Piston displacement | 239.2 cu. in. |
| Compression ratio | 6.5 to 1. |
| Transmission ratios: | |
| 1st | 2.67 to 1. |
| 2d | 1.66 to 1. |
| 3d | 1 to 1. |
| Rear axle ratio | 4.10 to 1. |
| Maximum gross horsepower. | 96 at 3400 r. p. m. |
| Maximum net horsepower. | 90 at 3400 r. p. m. |
| Maximum gross torque | 191 at 1200 r. p. m. |
| Maximum net torque | 186 at 1000 r. p. m. |

The horsepower and torque data, taken from curves in the Manufacturer's Shop Manual, are shown in table 1.

## *Summary of Basic Data*

The results for each test route are summarized in table 2. This summary forms the basis for a discussion of the operating characteristics of the test car on freeways and the parallel major highways, and for a brief résumé of the findings for the four special studies. It contains the average rates of speed and fuel consumption, the average engine torque, and the average throttle opening for each test method (average or attempted speed). The average engine torque and throttle opening were determined by weighting the percentage of the total trip time recorded in each class interval with the midpoint value of the given class interval.

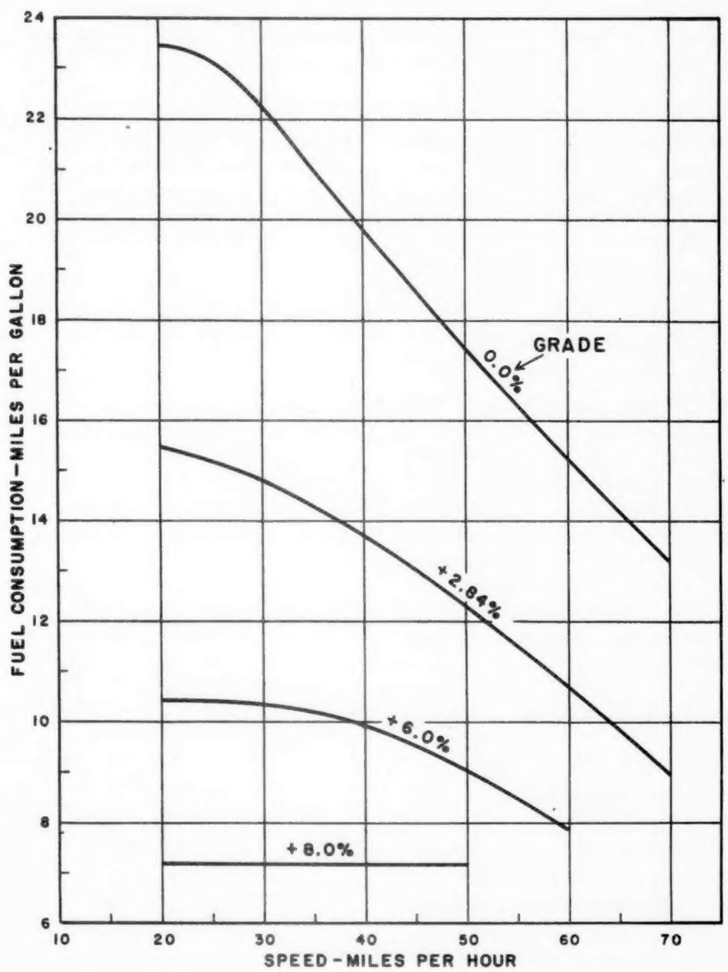



*Figure 18.—Fuel consumption of test car ascending uniform grades at sustained speeds.*

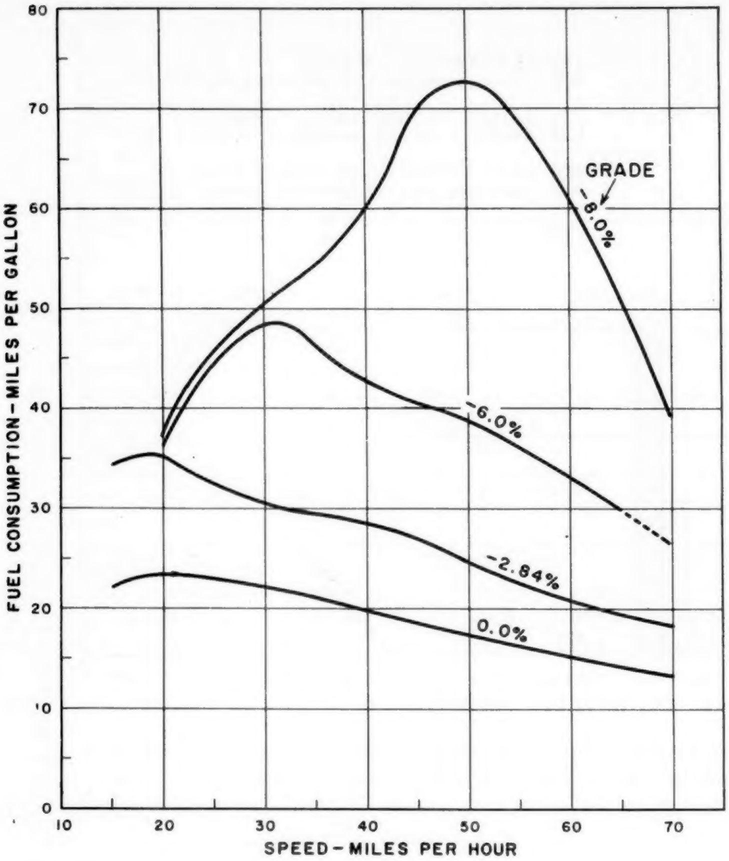



*Figure 19.—Fuel consumption of test car descending uniform grades at sustained speeds.*

Correction factors derived from the results of the fuelmeter calibration tests were applied to the observed rates of consumption to produce the values shown in table 2; except where no correction was warranted, and except in the cases of intersection and traffic light studies (facilities 8 and 9). In the latter instances, reliable factors could not be developed, because the test car operated a high percentage of the time at speeds less than 30 miles per hour.

Also included in table 2 are braking data which show the percentage of time spent in braking, the maximum class interval in which time was recorded, and a time factor. The vehicle was considered to be braking when the deceleration rate was more than 3 feet per second per second. The time factor is a ratio of the number of seconds recorded in class intervals of over 0–3 feet per second per second and the length of the test route in hundreds of miles.

## *The Freeway Studies*

### Speed and fuel consumption

The rates of fuel consumption and speed, shown in table 2 for freeways and parallel highways, are compared in figures 11 and 12. The term "average" over a bar indicates that the rate of fuel consumption or speed was obtained by driving the average test method. In figure 11, the three major highways are classed as rural, although they pass through numerous urban areas in New Jersey and Maine. The two parallel routes, identified in figure 12, include a substantial percentage of urban mileage.

For studies involving the New Jersey and Maine Turnpikes and the western section of the Pennsylvania Turnpike, the freeway was run with attempted speeds of 40, 50, and 60 miles per hour, and the parallel routes by the average test method. In the case of the middle Pennsylvania Turnpike study, both routes were run with the attempted speed test method—the freeway at speeds of 40, 50, and 60 miles per hour, and the major highway at speeds of 30, 40, and 50 miles per hour. The average test method was used for both the Shirley Memorial Highway and its parallel routes.

In this report it was assumed that the speed and fuel consumption rates observed on U. S. 11 and 30 in Pennsylvania for the attempted speed of 50 miles per hour approximated the performance that would have been obtained by the average test method. This was necessary because the traffic on many parts of this route was too light to use the average method of test. Values plotted in figure 11 for this route were based on the results which include the operations in the six major towns. The exclusion of these towns, as shown in table 2, increased the average speeds especially for the attempted speed of 50 miles per hour, but did not materially change the rates of fuel consumption.

From the comparisons in figures 11 and 12, except for the Shirley Memorial Highway, it is possible to gain an idea of the overall travel speeds that must be driven on the freeways to obtain a rate of fuel consumption that approximately equals that obtained by the average test method on the parallel route. In the case of the New Jersey and Maine Turnpikes the average speed is indicated to be less than 50 miles per hour, and for the middle and western sections of the Pennsyl-

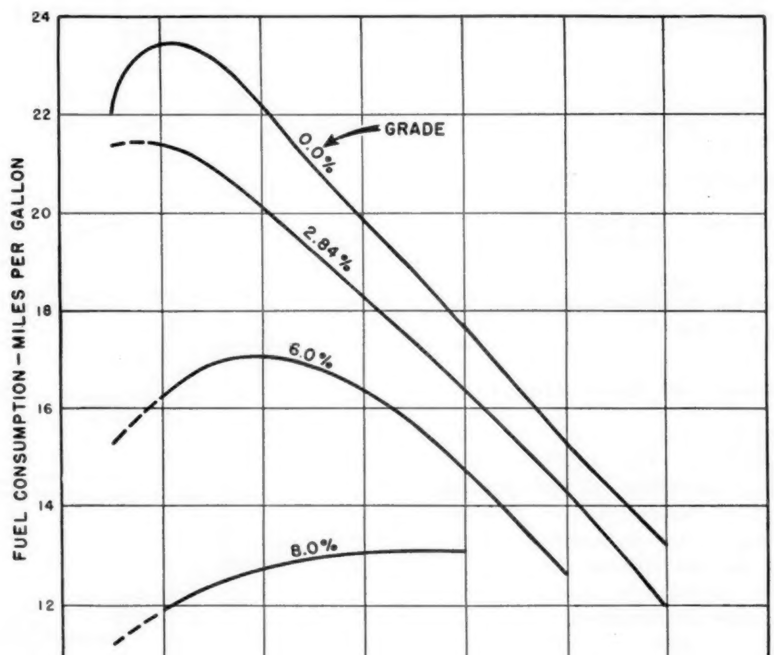



*Figure 20.—Composite fuel consumption of test car ascending and descending uniform grades at sustained speeds.*

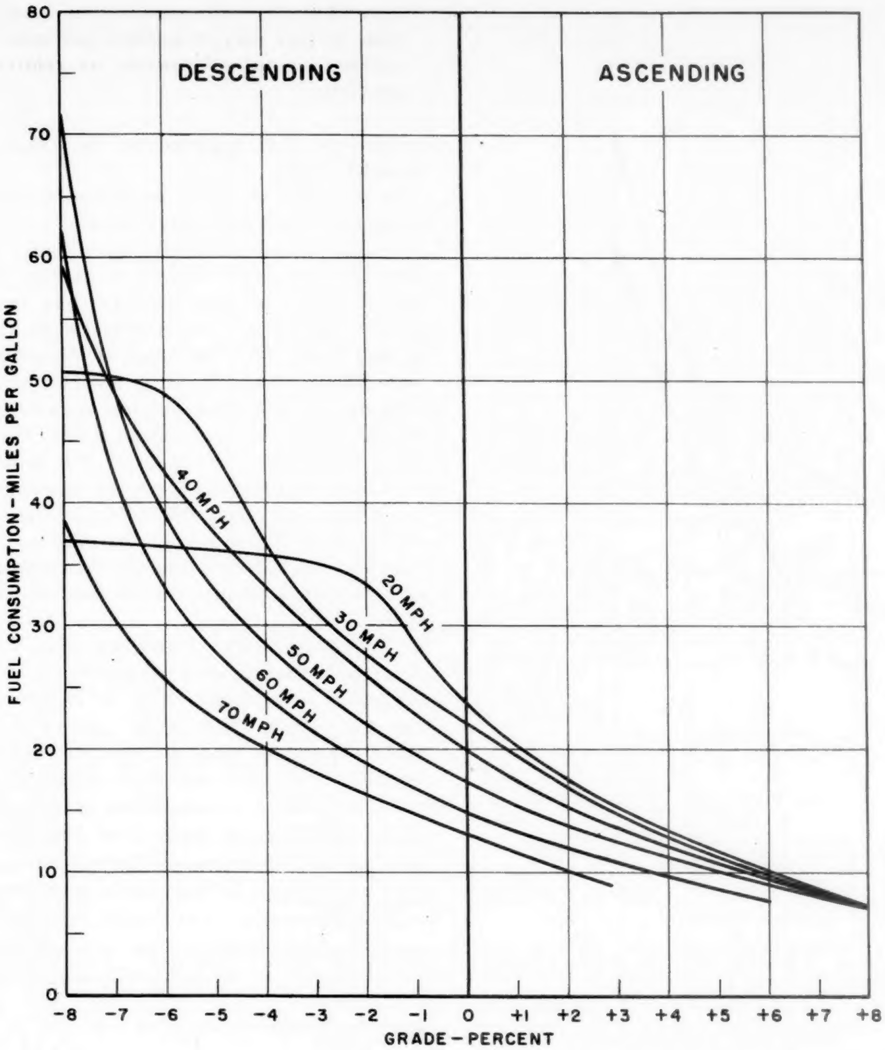



*Figure 21* **(Left).—*Directional fuel consumption of test car for various sustained speeds as related to gradient.***

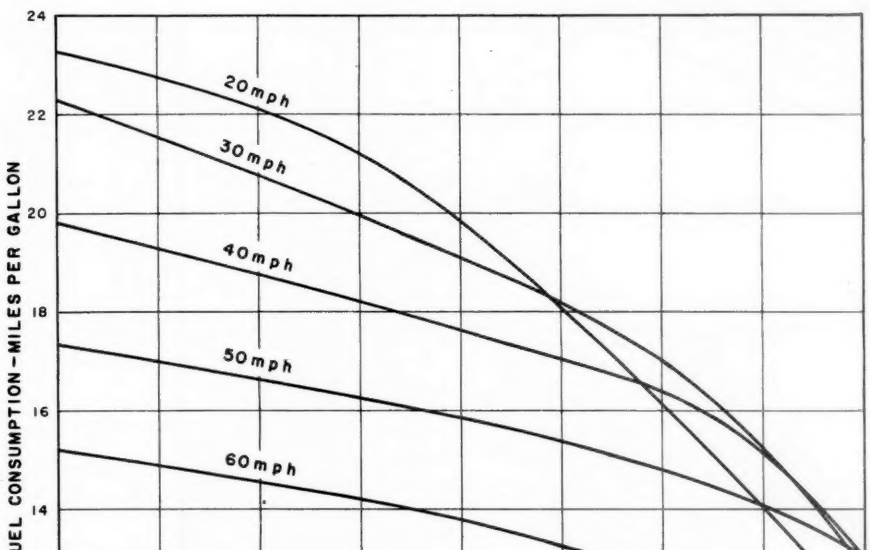



***Figure 22.—Composite fuel consumption of test car, in miles per gallon, for various sustained speeds as related to gradient.***

vania Turnpike it lies between 50 and 60 miles per hour. By actual interpolation of curves drawn to show the relation between the rates of fuel consumption and the average speeds obtained for the attempted speeds, the speeds which gave equivalent consumption rates were 48, 46, 54, and 53 miles per hour for the turnpikes in the order previously mentioned.

It is interesting to speculate on the reasons why the New Jersey and Maine Turnpikes must be traveled at slower speeds than the two sections of the Pennsylvania Turnpike in order to match the rates of consumption observed on the respective parallel routes. The principal reasons undoubtedly are that the major highway paralleling the middle Pennsylvania Turnpike has much more rise and fall than the routes which parallel the New Jersey and Maine Turnpikes, and the western Pennsylvania Turnpike involves considerably less traffic congestion with the resultant stop-and-go driving. The western section also has a small advantage over the parallel route in the degree of rise and fall.

By referring again to figures 11 and 12, it is seen that the average speed approximates the attempted speed in each instance. This fact indicates that very little traffic interference was encountered on the turnpikes up to an attempted speed of 60 miles per hour. Also, the rate of fuel consumption for a given attempted speed was nearly the same for each of the four turnpikes. For instance, the consumption rate for an attempted speed of 60 miles per hour was 15.4, 14.9, 15.1, and 15.6 miles per gallon for the New Jersey, Maine, and Pennsylvania Turnpikes, respectively.

### Road-user benefits

The road-user benefits in terms of travel time and fuel consumption that might result from the use of the freeway by the test car are indicated in table 3. For this analysis the test car was assumed to operate at the average overall travel speeds of passenger cars on the four turnpikes—55 miles per hour for the New Jersey and Maine Turnpikes, and 57 miles per hour for the two sections of the Pennsylvania Turnpike. The rate of fuel consumption shown in table 3 for each of the four routes was based on these average speeds. In all other instances, the results used were obtained with the average test method, which was designed to produce an overall travel speed that approximated that of passenger cars using the facility.

The travel time ratios in table 3, which are based on the average overall travel speeds and the indicated lengths of the test routes, show that use of the freeway resulted in considerable time saving in each case. The ratios range from 0.44 for the western Pennsylvania Turnpike to 0.73 for the middle Pennsylvania Turnpike. In other words, the travel time on the freeway was 44 and 73

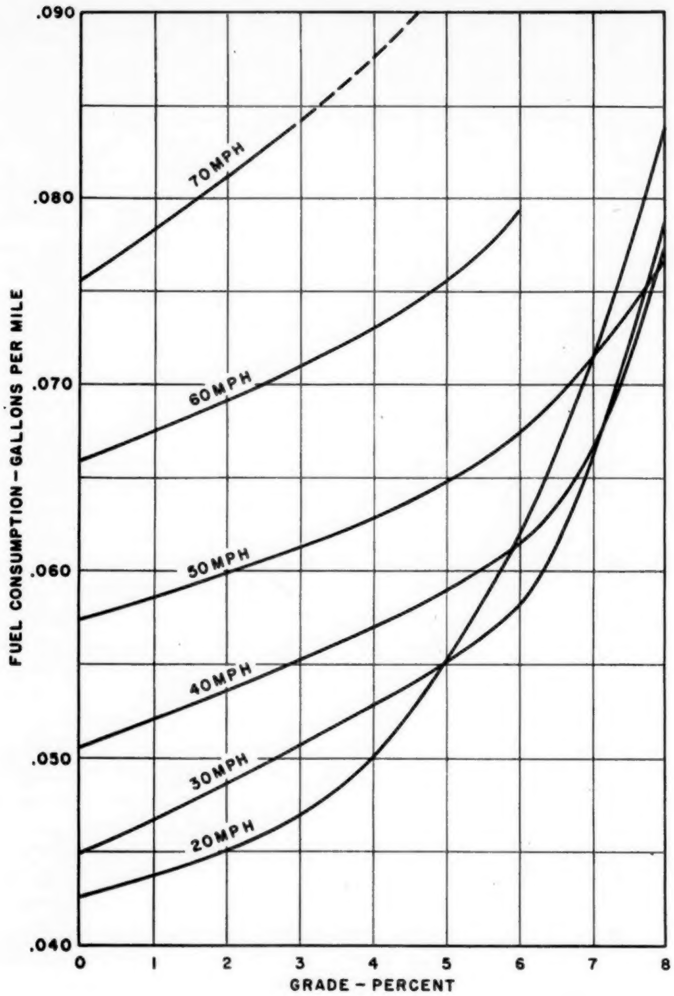



*Figure 23* (Left).—***Composite fuel consumption of test car, in gallons per mile, for various sustained speeds as related to gradient.***

percent of that required on the respective parallel routes.

In contrast the fuel consumption ratios, computed from the average rates of consumption and distances reported in table 3, show that the test car would burn slightly more fuel on three of the freeways than on the parallel highways. This is indicated by a ratio greater than 1.00. The rates of consumption were higher on the freeway in each instance, although the difference was less than one mile per gallon for the two sections of the Pennsylvania Turnpike. Because of the distance saved by using the freeways, the consumption in gallons was about the same for each pair of routes with the possible exception of the Maine study, in which case the ratio was 1.08, an 8 percent advantage for the parallel major route.

The western Pennsylvania Turnpike study, reported in table 2, shows that the rate of consumption through the cities of Wilkinsburg and Pittsburgh (12.9 miles) averaged 14.9 miles per gallon, and through the 40.9-mile section, classed as urban, it averaged 16.5 miles per gallon. A comparison of these rates with that shown in table 3 for the parallel freeway definitely shows that considerable traffic congestion is required to increase the rate of consumption above that found at the normal overall travel speeds on the Pennsylvania Turnpike. Of course, a considerable

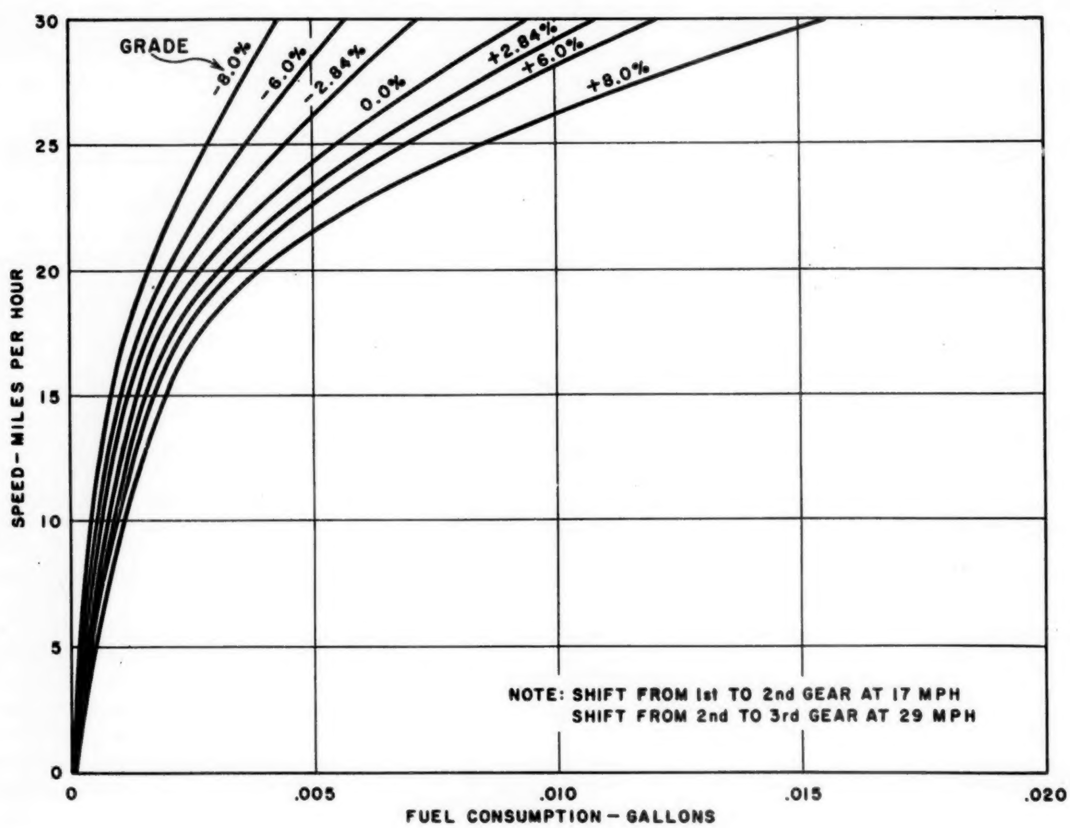



***Figure 24.—Fuel required for test car to accelerate with full throttle through all transmission gears from a standing start to 30 m. p. h. on various upgrades and downgrades.***

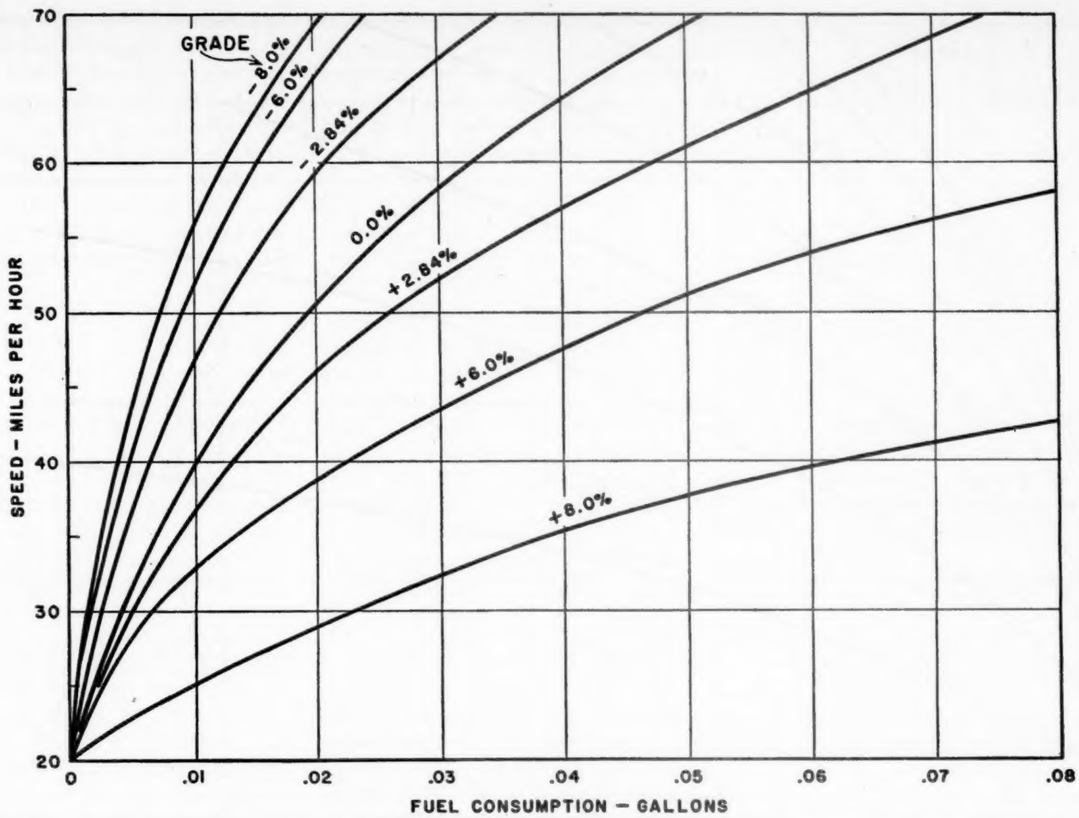



*Figure 25.—Fuel required for test car to accelerate in third gear with full throttle from 20 m. p. h. to higher speeds on various upgrades and downgrades.*

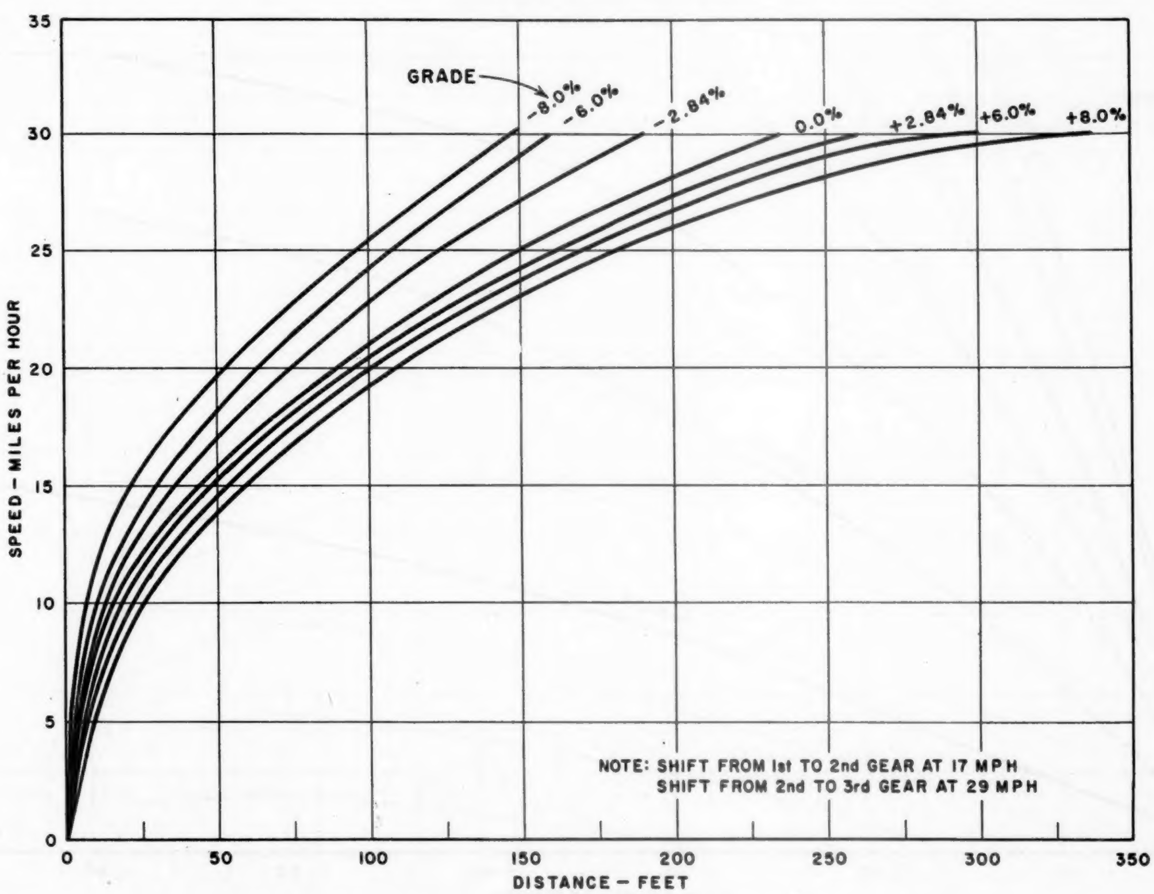



*Figure 26.—Distance required for test car to accelerate with full throttle through all transmission gears from a standing start to 30 m. p. h. on various upgrades and downgrades.*

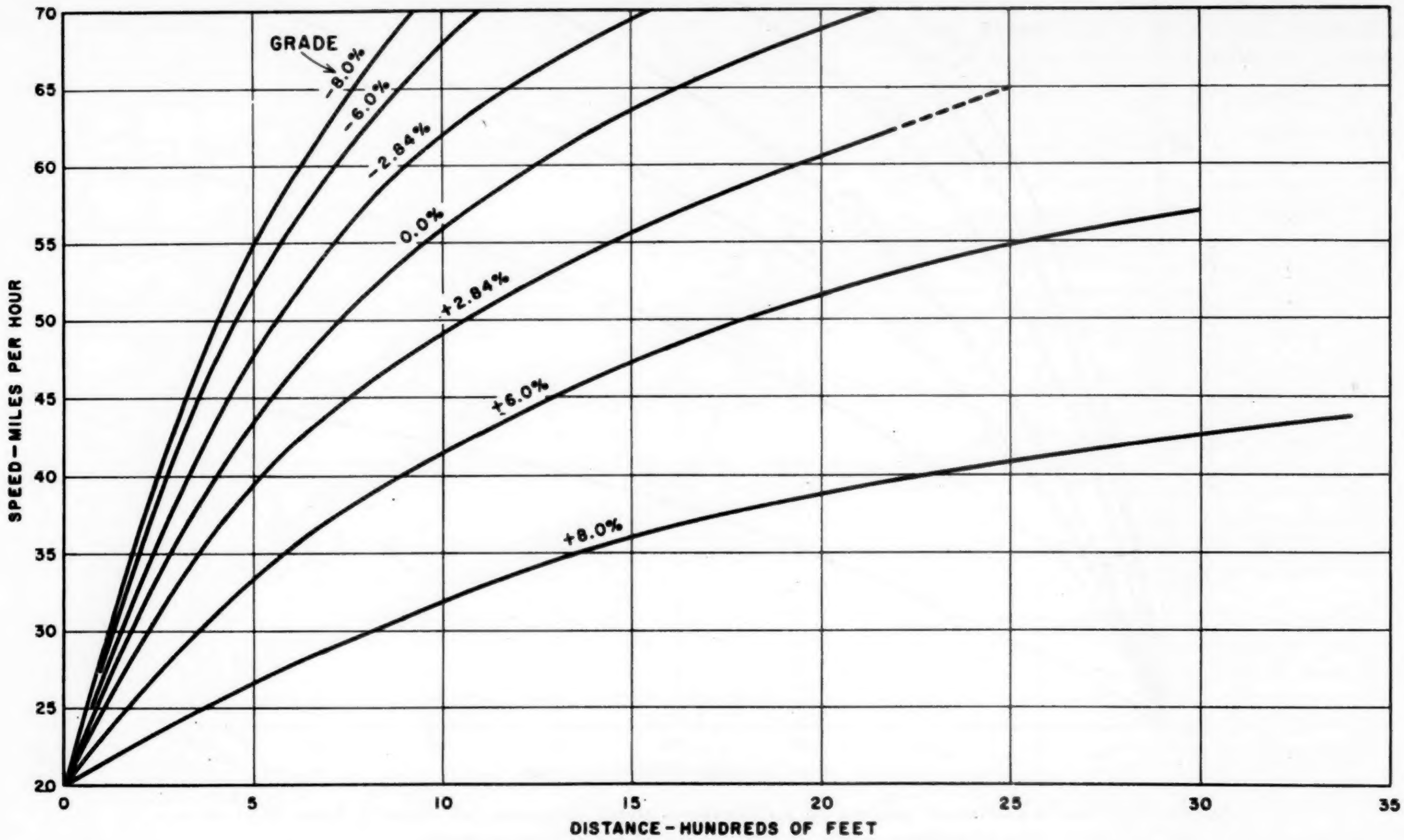



*Figure 27.—Distance required for test car to accelerate in third gear with full throttle from 20 m. p. h. to higher speeds on various upgrades and downgrades.*

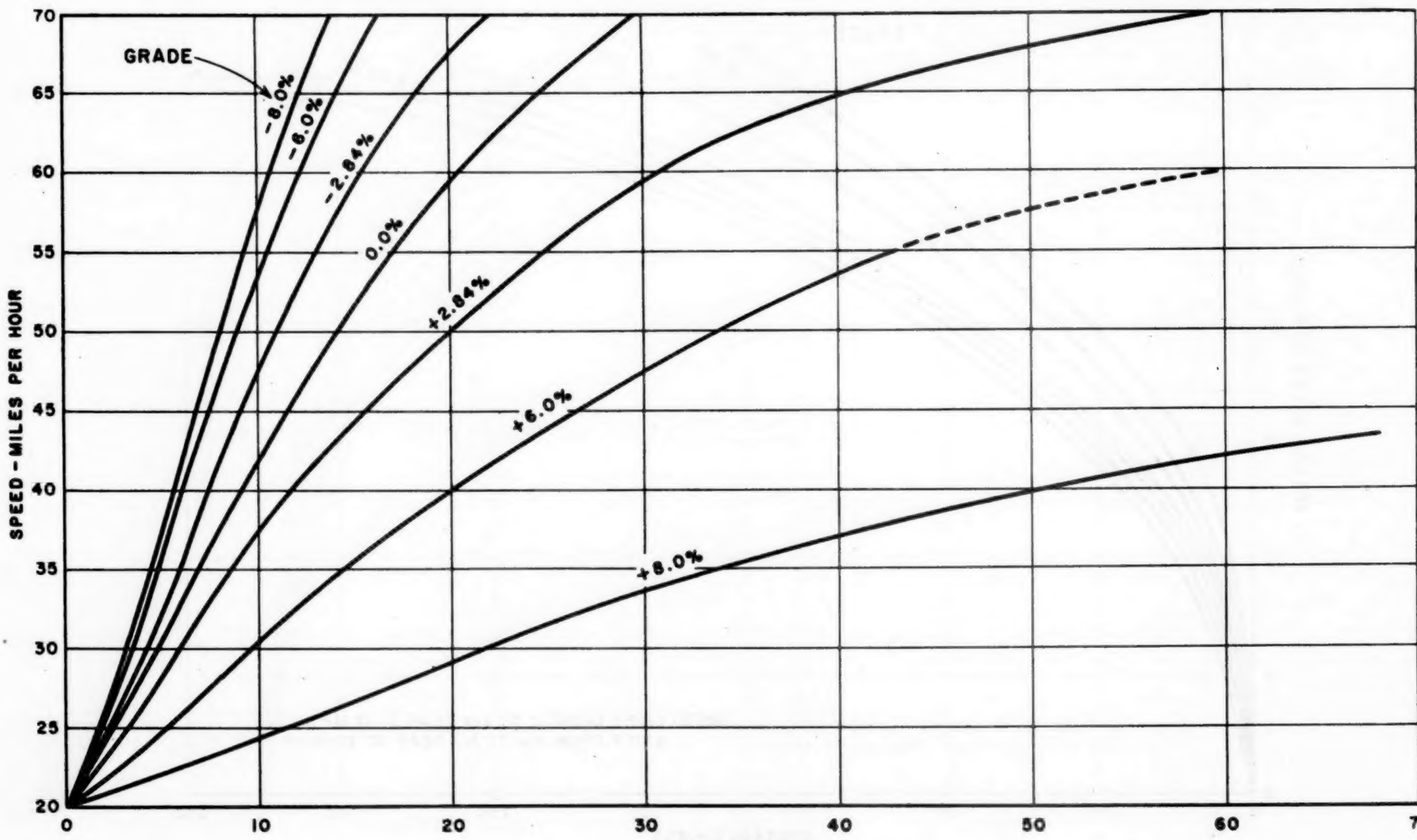



*Figure 28.—Time required for test car to accelerate in third gear with full throttle from 20 m. p. h. to higher speeds on various upgrades and downgrades.*

saving in fuel would be realized by operating at lower speeds on the Turnpike.

In the case of the New Jersey and western Pennsylvania studies, the parallel major highway was traveled before and after the opening of the turnpike. The results of these before and after studies are shown in table 2. They indicate that the opening of the turnpikes did not materially affect passenger car performance on the older routes.

### Time and fuel distribution by speed

Two typical examples of the great contrast between vehicle operation on a freeway and on a major highway are shown in figure 13 for the New Jersey routes, and in figure 14 for the western Pennsylvania routes. In each of the two freeway examples, about 98 percent of the time for the attempted speed of 60 miles per hour was spent in the 57 to 68 mile-per-hour group. In the case of the parallel major highways the time was distributed over a much wider range which indicated a great number of speed changes.

There was also a considerable difference between the time distribution for the route paralleling the New Jersey Turnpike (figure 13) and for the route paralleling the western Pennsylvania Turnpike (fig. 14). In the former instance, about 9.6 percent of the time was spent at speeds below 24 miles per hour, and in the latter, the corresponding value was 38.9 percent. This wide variation in time distribution helps to explain the differences between the time and fuel consumption ratios shown in table 3 for the two sets of routes.

The distribution of time, shown in the upper portions of figures 13 and 14, is compared with the distribution of fuel in figure 15. An interesting point is the small percentage of fuel that was consumed below a speed of 24 miles per hour. On the route through Pittsburgh where the average speed was 26.4 miles per hour, only 23.9 percent of the fuel was burned below a speed of 24 miles per hour. About 10 percent of the time was spent in the 0 to 5 mile-per-hour class interval and only 2.5 percent of the fuel was used in the same class interval.

### Built-in vehicle characteristics

One of the purposes of the study was to determine to what extent certain built-in vehicle characteristics were used in normal operation. The manner of conducting the tests precludes the use of speeds as a factor in this respect, except for the "average" runs made on parallel major highways. The percentage of time spent in each range of deceleration, engine torque, and throttle opening for the attempted speeds of 60 miles per hour, however, do indicate to some degree the normal use of brakes and power at average speeds slightly greater than the average overall travel speed of normal freeway traffic.

On the test routes which were operated with the average test method, the 57 to 68 miles-per-hour class interval was the highest speed in which any time was recorded. The percentage of time in this interval was less than 0.1 percent except for U. S. 130, 1, and 9 in New Jersey and the Shirley Memorial Highway in Virginia, where it was 8.0 and 7.4 percent, respectively.

The most surprising results are probably those shown in table 2 for the use of brakes. It is seen that the percentage of time spent in braking was practically nil for the freeways and rather insignificant for the parallel highways. The maximum deceleration recorded was in the range of 14–16 feet per

**Table 4.—Comparison of instantaneous acceleration rates for various speeds**

| Speed | Acceleration | |
|---|---|---|
| | Average vehicle | Test vehicle |
| *M. p. h.* | *M. p. h./sec.* | *M. p. h./sec.* |
| 20 | 2.5 | 2.0 |
| 25 | 2.5 | 2.1 |
| 30 | 2.5 | 2.2 |
| 35 | 2.5 | 2.3 |
| 40 | 2.3 | 2.2 |
| 50 | 2.0 | 1.8 |
| 60 | 1.5 | 1.4 |
| 70 | 1.0 | .8 |

second per second. Since the test vehicle by actual stopping-distance tests was capable of an average deceleration rate of 25.3 feet per second per second, only about 60 percent of the built-in braking force was used during any test.

Even though there was little time spent in braking on any route, a comparison of the time factors does indicate a sizable advantage for the freeways in this respect. For example, the time factor on the New Jersey Turnpike for an attempted speed of 60 miles per hour was 5.3 as compared with 181.2 for the parallel route before the opening of the Turnpike.

The average values of composite engine torque and throttle opening, shown in table 2, indicate that only a small portion of the built-in torque and power was normally utilized on any of the tests. This is emphasized by the time distributions shown in figures 16 and 17 for the three tests with the highest average engine torque and throttle opening. Time was seldom recorded in the highest two class intervals of engine torque (more than 77 percent) or in any class interval of throttle opening above 50 percent.

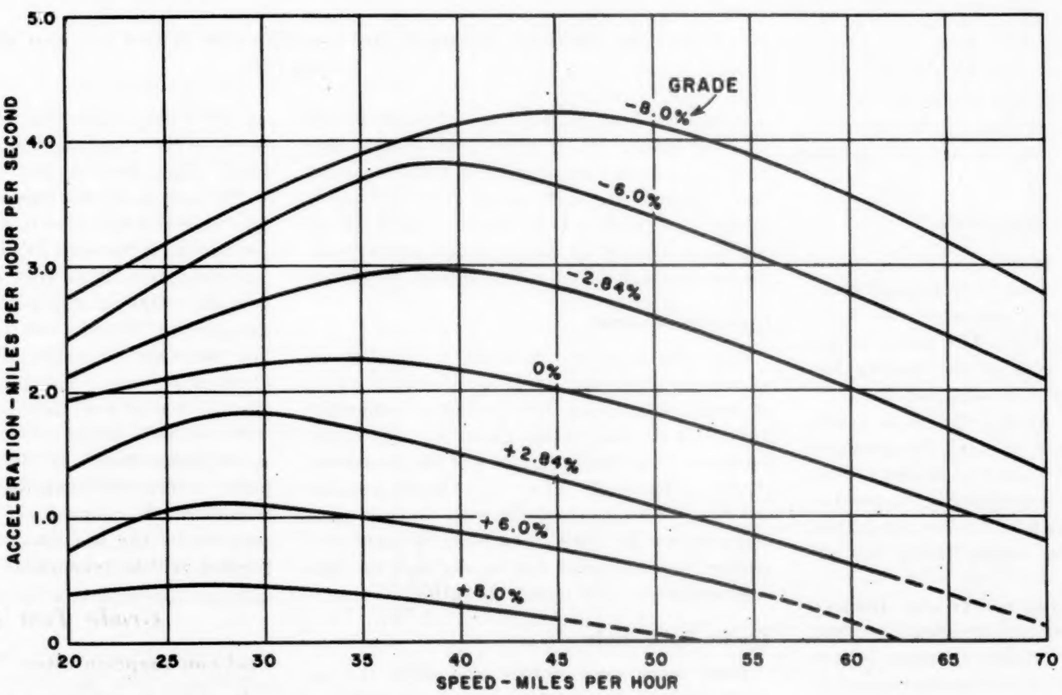



*Figure 29.—Average instantaneous acceleration rates at various speeds for test car operating in third gear on various upgrades and downgrades.*

The results shown in figures 16 and 17 were observed on three test routes with decidedly different profile characteristics. Operations on the New Jersey Turnpike were most consistent as indicated by about 75 percent of the time being spent in the engine torque range of 33 to 55 percent and about 90 percent of the time in the throttle opening range of 20 to 39 percent. In contrast, the time was distributed over a much wider range of both percentage of engine torque and throttle opening in the case of U. S. 40 which has a series of long steep grades.

Based on the data contained in table 2 and on the average overall travel speeds shown in table 3, the average engine torque and throttle opening observed on a major parallel highway were appreciably less than the average values observed on the corresponding freeway. For example, the average engine torque was 31.4 percent on U. S. 130, 1, and 9 in New Jersey and 41.2 percent by interpolation on the New Jersey Turnpike.

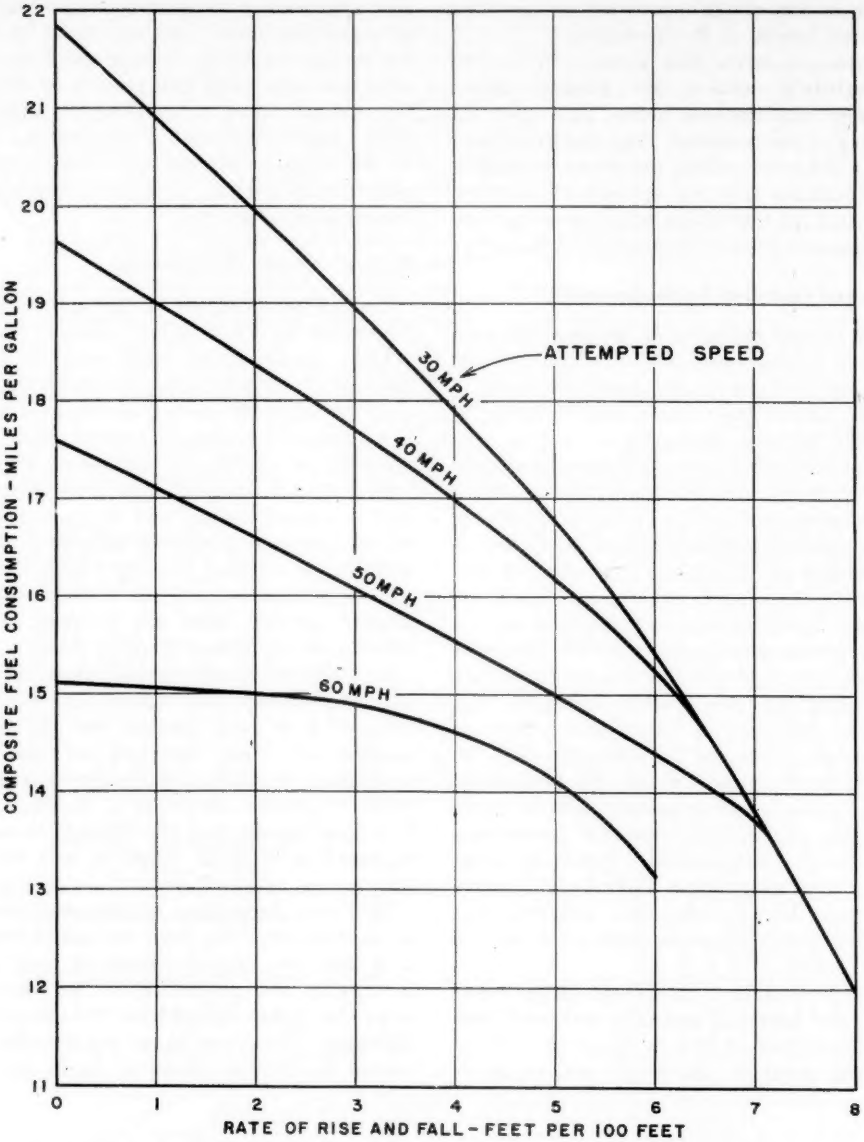



*Figure 30.—Relation between fuel consumption of test car and the rate of rise and fall.*

## *Résumé of Special Studies*

### U. S. 40 in Maryland

From a study made in 1947 between Hagerstown and Frederick, Md., it was found that the average speed of passenger cars was 33.6 miles per hour on the old section of U. S. 40 before the opening of the new section, and 42.5 miles per hour on the new section. For this reason the fuel consumption was measured on the old section by attempting to drive the average speed of 33.6 miles per hour in accordance with operating practices recorded at the time of the earlier tests. It is seen in table 2 that the average rate of fuel consumption was 16.6 miles per gallon on the old section at an average speed of 35.9 miles per hour. This rate compares with one of 17.1 miles per gallon determined for the average speed of 42.5 miles per hour by interpolating the rates measured on the new road for attempted speeds 40 and 50 miles per hour. The elimination of congestion created mostly by slow-moving trucks on steep grades appeared to result in a slight saving in fuel consumption.

### Washington, D. C., to Annandale, Va.

The results shown in table 2 for this route are included in the report only for reference use, since the original purpose of the study has already been served.[3] The route which led to Annandale by way of the Shirley Memorial Highway was far superior in average speed especially during the peak traffic period. Also, the rate of fuel consumption by way of the Shirley Memorial Highway was lower during the peak period, 16.4 miles per gallon as compared with 15.4 miles per gallon, but approximately the same during the off-peak period.

The performance was not greatly reduced by heavier traffic on the freeway section, whereas it was materially reduced in the case of the section with intersections at grade. Also, the difference in performance on the two sections during the off-peak period was not great. It appears that sizable savings in fuel consumption may result in peak traffic periods through use of freeways under urban conditions of operation. This is, of course, contrary to the findings already reported for high-speed operations on freeways.

### Intersection study

The results shown in table 2 (facility 8) need no explanation, except that the true rate of fuel consumption was probably somewhat higher than the value given in the table, because of the characteristics of the fuelmeter shown in figure 10. It was previously pointed out that the observed rates of consumption were shown in table 2 because reliable correction factors could not be derived for this predominantly low-speed operation.

### Traffic light study

Tests were made before and after the installation of 11 traffic-actuated signals on the most congested section of Columbia Pike. The results are summarized in table 2 (facility 9). The comments just made about the rates of fuel consumption for the intersection study apply also to this study.

The pertinent findings were that the average overall travel speed was reduced about 5 percent and the rate of consumption was increased about 12 percent during the off-peak periods. During the peak period, the average overall travel speed was about the same but the rate of consumption was lower by about 6 percent. The purpose of the signal installation was to facilitate the cross traffic with as little interference as possible to the main traffic flow. If the movements of the cross traffic were expedited, as it would be reasonable to assume, it appeared that the purpose of the installation had been accomplished within reasonable limits.

## *Grade Test Results*

### Fuel consumption rates

In order to add to the scant data that have been reported for fuel characteristics of modern passenger cars on a wide variety of

[3] See footnote 1, page 182.

**Table 5.—Savings in fuel consumption resulting from two methods of grade reduction**

| Grade reduction, in percent | Percentage of savings for sustained speeds of— | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 m. p. h. | | 40 m. p. h. | | 50 m. p. h. | | 60 m. p. h. | |
| | Method I [1] | Method II [2] | Method I | Method II | Method I | Method II | Method I | Method II |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 8–6 | 16.7 | 25.7 | 12.7 | 20.2 | 7.5 | 11.3 | ---------- | ---------- |
| 8–4 | 15.2 | 33.4 | 10.9 | 26.0 | 6.0 | 17.6 | ---------- | ---------- |
| 8–3 | 13.1 | 36.5 | 8.7 | 28.0 | 4.9 | 19.6 | ---------- | ---------- |
| 8–2 | 9.8 | 39.0 | 6.6 | 30.4 | 3.7 | 21.6 | ---------- | ---------- |
| 6–4 | 3.0 | 10.5 | 1.7 | 7.4 | 2.0 | 7.0 | 3.1 | 8.7 |
| 6–3 | 3.3 | 14.5 | 1.4 | 9.9 | 1.8 | 9.2 | 3.7 | 11.9 |
| 6–2 | 2.7 | 17.9 | 1.5 | 12.8 | 1.5 | 10.4 | 2.6 | 13.7 |
| 4–3 | .9 | 4.5 | .1 | 2.7 | .3 | 2.4 | 1.3 | 3.5 |
| 4–2 | 1.1 | 8.3 | .6 | 5.9 | .5 | 4.8 | .9 | 5.5 |
| 3–2 | .4 | 3.9 | .5 | 3.3 | .3 | 2.4 | 0 | 2.0 |

[1] No reduction in rise and fall.
[2] Reduction in rise and fall.

gradients, the test car was driven on grades ranging from 0 to 8 percent. The vehicle was operated in direct gear at sustained speeds ranging from 15 to 70 miles per hour and was accelerated in various gears from a standing start to the highest practicable speed.

The rates of consumption in miles per gallon for the sustained speeds are shown in figure 18 for ascending, and figure 19 for descending four uniform grades. The composite consumption, which combines the results shown in figures 18 and 19, is given in figure 20. For the uphill tests, the fuel consumption decidedly increased at a slower rate with speed as the grade increased. This occurs mainly because air resistance, which increases approximately with the square of the speed, is constant for each grade and becomes a smaller portion of the total resistance to motion as the grade increases. It is seen that consumption remained almost constant for ascending the 8 percent grade, and actually decreased slightly with speed for the composite relation. The test car could not sustain a speed of 65 miles per hour on a 6-percent grade or 55 miles per hour on the 8-percent grade.

The directional fuel consumption shown in figures 18 and 19 and the composite fuel consumption shown in figure 20 are replotted in more usable form in figures 21 and 22, respectively. From these curves it is possible to determine easily the fuel consumption for any degree of gradient at a given sustained speed. In considering the composite consumption, the interesting point is that the rate of consumption increases at a fairly uniform rate with an increase in grade up to a grade of 6 percent for all except the 20-mile-per-hour sustained speed. Above 6 percent, the increase is at a faster rate which indicates that the reduction of grades above 6 percent should result in a saving in fuel consumption for the test vehicle, even if the rise and fall is not reduced. The relations for composite consumption shown in figure 22 are plotted in terms of gallons per mile in figure 23 for later use in this report.

Accumulative fuel curves for accelerating on the level and on various plus and minus grades with full throttle from a standing start to 30 miles per hour are shown in figure 24. Two gear shifts were made, one at 17 miles per hour and one at 29 miles per hour. Actually the vehicle operated in third (direct) gear only from 29 to 30 miles per hour. Similar relations for accelerating in third gear from 20 miles per hour to the highest practical speed are shown in figure 25. Since the fuel consumption is accumulated with speed, it is possible to determine from these data the fuel consumed for accelerating between any two given speeds.

These data should have application to the problem of estimating the cost savings that might accrue to users of passenger cars by the elimination of traffic congestion or other interruptions to the smooth flow of traffic, which cause the driver to accelerate from a reduced speed to the desired running speed. An example would be the economic analysis of the congestion caused by slow-moving trucks on hills.

Another useful value of fuel consumption obtained for the test car was the fuel consumed while idling. The consumption at an idling engine speed of approximately 460 revolutions per minute was 0.4 gallon per hour. At an engine speed of 600 revolutions per minute it was about 0.5 gallon per hour.

### Acceleration rates

The distance required to accelerate with full throttle between any two speeds can be determined from the curves shown in figure 26 for accelerating through first and second gears from a standing start to 30 miles per hour, and in figure 27 for accelerating in third gear from 20 miles per hour to the highest practicable speed. For example, to obtain the distance required to accelerate up a 6-percent grade from 30 to 50 miles per hour, the accumulative distance of 350 feet at 30 miles per hour is subtracted from the accumulative distance of 1,800 feet at 50 miles per hour. The answer is 1,450 feet.

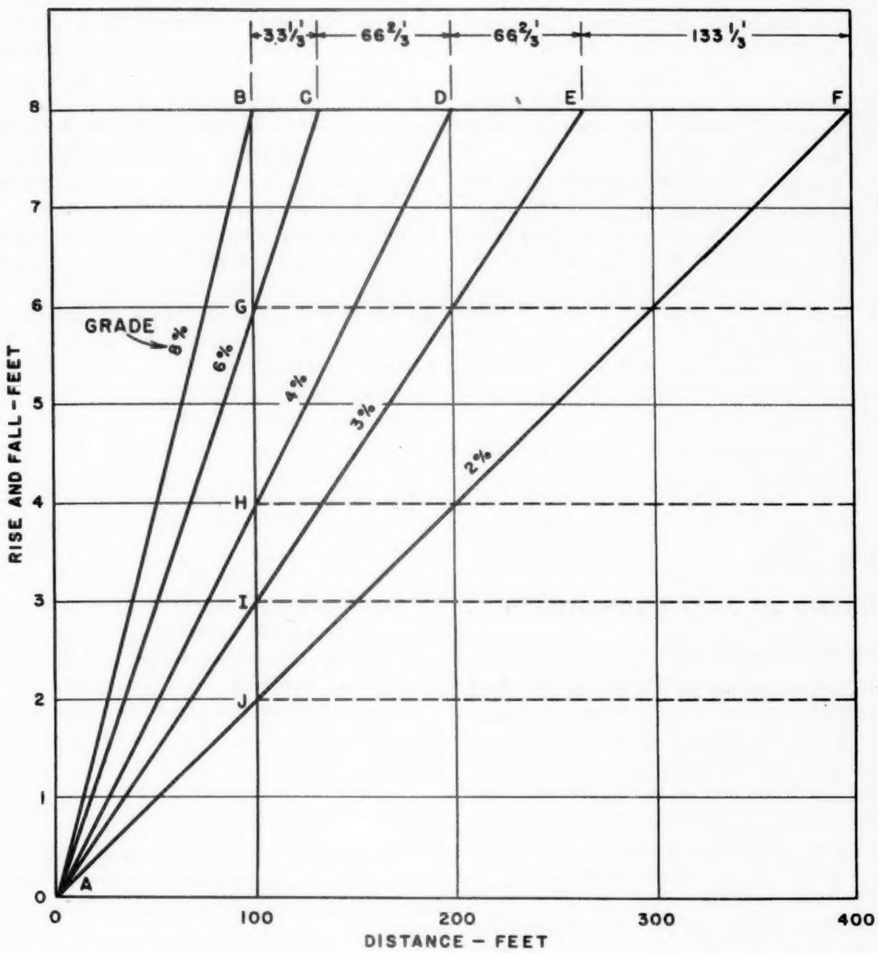



*Figure 31.—Example for determining savings in fuel consumption by two typical methods of grade reduction.*

**Table 6.—Summary of fuel consumption between Frederick and Hagerstown, Md., measured and computed by various methods for attempted sustained speed of 50 miles per hour**

| Sections | Section length | Rise and fall rate | Fuelmeter measurement | | | | Individual grade method | Rise and fall method | | Grade classification method |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | July 1951 | Aug. 1952 | Sept. 1952 | Average | | Rise and fall relation | Individual grade relation | |
| | *Miles* | *Ft./100 ft.* | *Gal.* | *Gal.* | *Gal.* | *Gal.* | *Gal.* | *Gal.* | *Gal.* | *Gal.* |
| A–B | 3.5 | 3.8 | 0.200 | ----- | 0.220 | 0.210 | 0.224 | 0.223 | 0.219 | 0.223 |
| B–C | 1.8 | 4.5 | .106 | ----- | .117 | .112 | .119 | .118 | .115 | .118 |
| C–D | 4.1 | 3.8 | .231 | ----- | .252 | .242 | .264 | .262 | .256 | .266 |
| D–E | 2.4 | 5.7 | .149 | ----- | .160 | .154 | .167 | .164 | .160 | .165 |
| E–F | 2.6 | 5.2 | .156 | ----- | .167 | .161 | .173 | .174 | .170 | .172 |
| F–G | 6.6 | 2.2 | .368 | ----- | .390 | .379 | .399 | .400 | .398 | .399 |
| Total | 21.0 | 3.7 | 1.210 | 1.318 | 1.306 | [1] 1.278 | 1.346 | [2] 1.333 | [2] 1.310 | 1.343 |
| Variation from burette measurement [3] pct. | | | −5.5 | +3.0 | +2.0 | −0.2 | +5.2 | +4.9 | +2.3 | +5.0 |

[1] Not a summation of values for intermediate sections.
[2] Based on rate of rise and fall for total section, and not a summation of values for intermediate sections.
[3] Burette measurement, August 1952, 1.280 gallons.

Similar relations between speed and accumulative time are shown in figure 28 for the same plus and minus grades. The time required to cover the distance of 1,450 feet was determined to be approximately 24 seconds.

The relations in figures 25 and 27 may be used to determine the average rate of fuel consumption for accelerating between two speeds. For full throttle acceleration on a plus 6-percent grade from 30 to 50 miles, the rate was 6.9 miles per gallon. This was determined by dividing the distance in miles (fig. 27) by the fuel in gallons (fig. 25). The rate of 6.9 miles per gallon compares with one of 9.0 miles per gallon, read from figure 18 for a sustained speed of 50 miles per hour on an upgrade of 6 percent.

The instantaneous acceleration rates at various speeds are shown in figure 29. The peak acceleration on the level occurs at a road speed of 35 miles per hour which approximates the speed of peak torque. The shape of the acceleration curve is similar to the shape of the maximum torque curve and this should be the case, since acceleration is proportional to torque. The acceleration rates for the test vehicle are very similar to those obtained in a previous study for an average of 53 vehicles.[4] A comparison of the instantaneous rates for various speeds of the test vehicle and for the average of 53 vehicles is shown in table 4.

## *Analyses of Fuel Consumption*

### Rise and fall relations

The relations between fuel consumption and rise and fall, shown in figure 30 for attempted speeds of 30, 40, 50, and 60 miles per hour, were derived from the rates of composite fuel consumption observed on the individual test sections of the New Jersey Turnpike, Maine Turnpike, Pennsylvania Turnpike (both sections), Shirley Memorial Highway, U. S. 30 and 11 in Pennsylvania, and U. S. 40 in Maryland. If the average speed for a test section was not within about 5 percent of the attempted speed, the rate of fuel consumption was not used in this analysis.

The average curves shown in figure 30 for 30, 40, 50, and 60 miles per hour were based on 35, 79, 74, and 46 observations, respectively. There was a rather wide dispersion of the observed points about each of the curves. The standard errors of estimate in miles per gallon were 0.76 for 30 miles per hour, 0.79 for 40 miles per hour, 0.63 for 50 miles per hour, and 0.35 for 60 miles per hour. Part of the wide scatter of data about the curves was undoubtedly due to variations in performance of the test car during the period of tests, shown previously in figure 9. Another factor contributing to the large deviation was the inability to develop reliable correction factors for the varying accuracy of the fuelmeter, shown in figure 10.

The relations established between the rate of rise and fall and the rate of fuel consumption were very similar to those shown in figure 22, which were determined for sustained speed operation on short uniform grades. They provide a rather easy method for estimating the fuel used on any section of road. The particular advantage is that any combination of grades can be considered at one time by determining the total rise and fall for the highway section. A disadvantage is the error that results when the length of the very steep grades is an appreciable portion of the total length being considered. This error results because the composite effect of one foot of rise and fall, as shown in figure 30, is appreciably greater for the rates of rise and fall above 6 feet per hundred feet. The rate of fuel consumption was also shown in figure 22 to increase at a faster rate for grades over 6 percent.

### Grade reduction methods

The savings in fuel consumption that result by reducing grades without a reduction in rise and fall, and with a reduction in rise and fall are indicated in table 5. They were computed from the example shown in figure 31 and the rates of fuel consumption (gallons per mile) shown in figure 23. In order to clarify the mechanics of the analysis, the problem of reducing an 8- to a 4-percent grade is described in detail for a speed of 30 miles per hour.

Figure 31 shows that if the reduction of the 8-percent grade is accomplished without a reduction in rise and fall, the saving in fuel would be the sum of the consumption on the 8-percent grade (AB) and the level section (BD), minus the consumption on the 4-percent grade (AD). The fuel consumed was 0.001983 gallon on AD (200 feet), 0.001491 gallon on AB (100 feet), and 0.000849 gallon on BD (100 feet). These values of consumption were determined by multiplying the length of the respective section in miles by the rate of consumption read for the specified grade from the 30-mile-per-hour curves in figure 23. The saving in fuel is thus 0.000357 gallon. The percentage of savings is 0.000357 gallon divided by 0.002340 gallon, or 15.2 percent.

If the reduction in the 8-percent grade is made by reducing rise and fall, the saving would be the consumption on the 8-percent grade (AB) minus the consumption on the 4-percent grade (AH). The consumption on AB (100 feet) was previously determined to be 0.001491 gallon. By using the rate of consumption shown in figure 23 for the 4-percent grade, the fuel consumed on AH (100 feet) was determined to be 0.000992 gallon. A saving of 0.000499 gallon or 33.4 percent resulted.

It is seen in table 5, that Method II always results in the largest saving. A reduction in grade by Method I appears to result in appreciable savings for grades in excess of 6 percent. However, grades of 6 percent or under must be reduced by Method II if any substantial saving is to be realized. It is emphasized that the savings shown in table 5 are based on the fuel characteristics of one passenger car, and that they could be materially different for other vehicles.

The differences between the two methods of grade reduction are very clearly shown in figure 32. The savings are those shown in table 5 for a sustained speed of 50 miles per hour. Except for the reduction of an 8- to a 6-percent grade, Method I is shown to be much inferior to Method II. Very little is gained by reducing grades of 6, 4, or 3 percent by Method I, or by reducing grades of 4 and 3 percent by either method. It can be readily seen that reducing grades per se may not result in appreciable savings in fuel consumption.

### Fuel computations

The 21.0-mile section of U. S. 40 between Frederick and Hagerstown, Md., was selected for checking various methods that can be used to measure and compute fuel consumption, because the lengths of steep grades constituted a sizable portion of the total length. This section of highway had a rate of rise and fall of 3.7, the highest of any test route studied. About 29 percent of its length was on grades of 5 percent or more, and about 15 percent on grades of 7 percent or greater.

[4] *Braking distances of vehicles from high speeds, and tests of friction coefficients*, by O. K. Normann. PUBLIC ROADS, vol. 27, No. 8, June 1953.

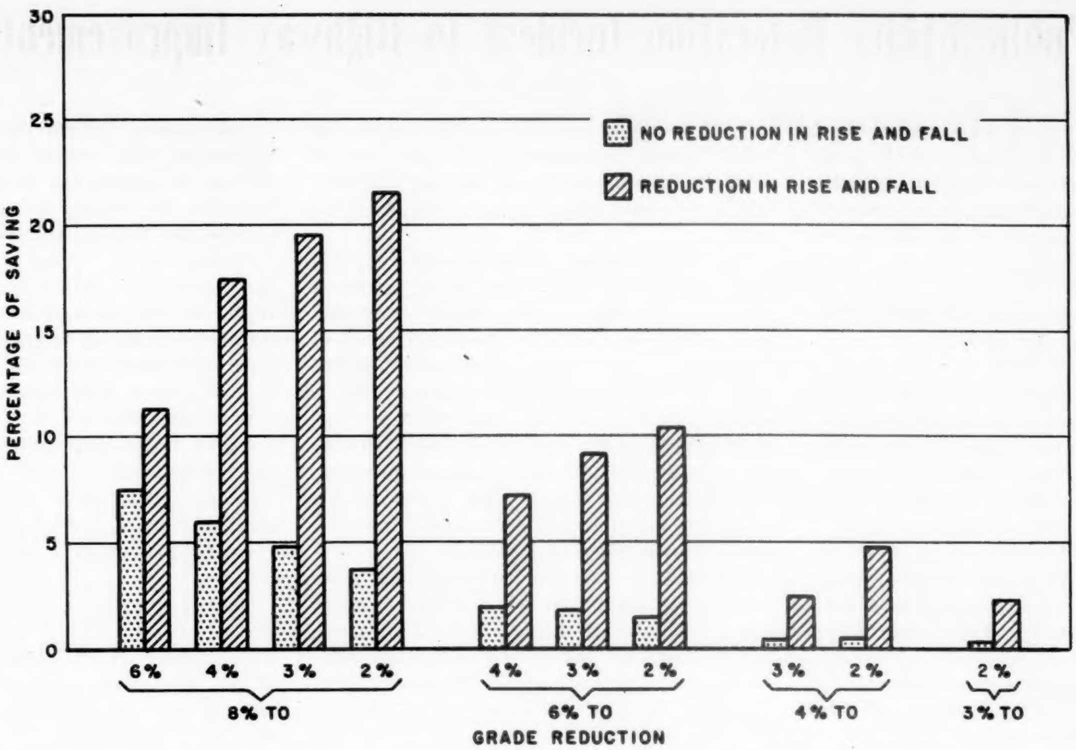



*Figure 32.—Savings in fuel consumption determined by two methods of grade reduction for a sustained speed of 50 m. p. h.*

The fuel consumption in gallons, determined by the various methods for an attempted speed of 50 miles per hour, is shown in table 6. Fuel was measured with a burette in one test, and with the fuelmeter in three tests. The fuel consumption was computed by two methods that use individual grades, and by two methods that use the rate of rise and fall, which have been called the composite or average grade by other investigators.

The values in the column headed "Individual grade method" are the summation of fuel consumption computed for each individual grade in the section. This method required 198 computations using the rates of fuel consumption shown in figure 23.

The "Grade classification method" is a simplified version of the method just discussed. The individual grades were grouped in four classes: 0 to 3 percent, 3 to 5 percent, 5 to 7 percent, and 7 to 9 percent. The total length in each class was then multiplied by the rate of fuel consumption in gallons per mile, obtained from figure 23 for the midpoint of the particular grade class. This method is not quite so laborious as the previous one and gave almost identical results.

The "Rise and fall method" required only one computation for a given section. The first column under this method contains values that were computed with the fuel consumption rates shown in figure 30 for various rates of rise and fall. The values in the second column headed "Individual grade relation" were based on the rates for individual grades shown in figure 23.

The fuel measured with the burette was used as a common base for comparative purposes. The percentage of variations from the burette measurement, shown in table 6, indicates that all methods gave results which were within reasonable limits of error. The much simpler "Rise and fall method" appears to be as good as, or better than, the two methods which require a solution for each individual grade. The results obtained with the fuelmeter also did not vary appreciably from those measured with the burette.

# Public Utility Relocation Incident to Highway Improvement

President Eisenhower on April 5, 1955, transmitted to Congress a report on the problems posed by relocation of public utilities made necessary by highway improvements. The report was prepared by the Bureau of Public Roads, in cooperation with the State highway departments and public utilities, at the direction of Congress, in section 11 of the Federal-Aid Highway Act of 1954.

The report, entitled *Public Utility Relocation Incident to Highway Improvement*, has been published as House Document No. 127, 84th Congress, 1st Session, and is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 25 cents a copy.

Traditionally, public utilities have established themselves along, and within, public highway rights-of-way. In general, the status of these installations has been covered by State constitutional or statutory authority. As a rule, where highway improvements require it, the public utility facilities are removed from one location within the highway right-of-way to another at the expense of the utilities themselves. As highway improvement and modernization increased, the utilities have claimed that these relocation costs imposed a greater and greater burden.

In its study of this problem the Bureau of Public Roads investigated both the cost of public utility relocation and the legal relationships which may affect the distribution of the costs.

The State highway departments reported that the total dollar value of all highway projects completed in the survey year 1953 was approximately $1.7 billion and involved 10,245 highway projects, aggregating 40,027 miles in length. The public utilities which cooperated in the study reported that they could identify 5,422 utility relocations in connection with 3,836 of these highway projects. The dollar value of this construction amounted to about $1.1 billion and involved nearly 14,000 miles of highway.

The utilities reported relocation costs for the year amounting to $35.5 million. More than 80 percent of this cost ($29.1 million) involved utilities located within the highway right-of-way. The remaining 20 percent ($6.4 million) was the cost of moving utilities located on their own private rights-of-way for much of which they were reimbursed in the same manner as any other property owner. Total costs were divided almost equally between projects in urban and rural areas—$15.2 million in urban areas and $13.9 million in rural areas. Of the reported $35.5 million relocation cost, nearly 90 percent was incurred in connection with the Federal-aid systems, the remainder on State highways outside the Federal-aid systems.

Among utility types, electric and power, and telephone together accounted for nearly 70 percent of the reported $35.5 million relocation cost, gas accounted for almost 14 percent, and water for some 11 percent. Some of these costs were reimbursable and agencies at different levels of government were involved in making payments. The bulk of the reimbursements were met by the State highway departments. Of a total reimbursement of more than $8.4 million, 86.5 percent, or nearly $7.3 million, was so returned to the utilities.

Data which the Bureau of Public Roads obtained from the State highway departments with respect to reimbursement for public utility relocation costs indicated that the total of State reimbursements for such costs was nearly $16 million. It is evident that the State highway department figures include many public utility highway relocation projects which were not included in the data reported by the public utilities. This is notably true of publicly owned utilities.

# Precast Concrete Bridge: A Motion Picture

The Bureau of Public Roads recently produced and released a new motion picture, ***A Record of Casting and Placement of a Precast Concrete Bridge***. The one-reel, 16-mm. sound and color film has a running time of 18 minutes.

The film illustrates, with scenes at an actual bridge site and with animated drawings, a method of bridge building which is growing in usage in this country. The nature of the forms for the precast concrete beams, deck slabs, and curb sections, and their use in the central casting yard, are demonstrated in detail. Driving of piles and construction of bent-caps at the bridge site, the placement of the precast units, and the final operations involved in completing the three-span structure are shown step by step.

The film may be borrowed by any responsible organization, without charge except for the nominal shipping costs, by writing to Visual Education, Bureau of Public Roads, Washington 25, D. C. The number of available prints is limited, so several alternate dates should be proposed in requesting loan of the picture. Loans can be made only for short periods of time.

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

# PUBLICATIONS of the Bureau of Public Roads

***The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.***

## ANNUAL REPORTS

Work of the Public Roads Administration:
1941, 15 cents. 1948, 20 cents.
1942, 10 cents. 1949, 25 cents.
Public Roads Administration Annual Reports:
1943; 1944; 1945; 1946; 1947.
(*Free from Bureau of Public Roads*)
Annual Reports of the Bureau of Public Roads:
1950, 25 cents. 1952, 25 cents. 1954 (out of print).
1951, 35 cents. 1953, 25 cents.

## PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.
Braking Performance of Motor Vehicles (1954). 55 cents.
Construction of Private Driveways, No. 272MP (1937). 15 cents.
Criteria for Prestressed Concrete Bridges (1954). 15 cents.
Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
Financing of Highways by Counties and Local Rural Governments, 1931–41. 45 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):
1945, 35 cents. 1948, 65 cents. 1951, 60 cents.
1946, 50 cents. 1949, 55 cents. 1952, 75 cents.
1947, 45 cents. 1950 (out of print). 1953, $1.00.
Highway Statistics, Summary to 1945. 40 cents.
Highways in the United States, *nontechnical* (1954). 20 cents.
Highways of History (1939). 25 cents.
Identification of Rock Types (1950). Out of print.
Interregional Highways, House Document No. 379 (1944). 75 cents.
Legal Aspects of Controlling Highway Access (1945). 15 cents.
Local Rural Road Problem (1950). 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.00.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.
Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.
Model Traffic Ordinance (revised 1953). 20 cents.

## PUBLICATIONS (Continued)

Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks, FP–41 (1948). $1.50.
Standard Plans for Highway Bridge Superstructures (1953). $1.25.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

## MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways together with the Federal-Aid Highway System (also shows in color National forests, parks, and other reservations). 5 by 7 feet (in 2 sheets), scale 1 inch equals 37 miles. $1.25.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

***Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.***

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938)
Bibliography on Land Acquisition for Public Roads (1947)
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23
Title Sheets for PUBLIC ROADS, volumes 24–27.

UNITED STATES
GOVERNMENT PRINTING OFFICE
DIVISION OF PUBLIC DOCUMENTS
WASHINGTON 25, D. C.

OFFICIAL BUSINESS





DEPARTMENT OF COMMERCE - BUREAU OF PUBLIC ROADS

# STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF JUNE 30, 1955

(Thousand Dollars)

| STATE | UNPROGRAMMED BALANCES | ACTIVE PROGRAM | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PROGRAMMED ONLY | | | PLANS APPROVED, CONSTRUCTION NOT STARTED | | | CONSTRUCTION UNDER WAY | | | TOTAL | | |
| | | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles |
| Alabama | $6,590 | $17,420 | $9,502 | 414.3 | $4,881 | $2,591 | 48.1 | $44,670 | $22,626 | 752.8 | $66,971 | $34,719 | 1,215.2 |
| Arizona | 1,879 | 3,837 | 2,900 | 102.1 | 3,324 | 2,345 | 53.2 | 8,641 | 6,324 | 162.7 | 15,802 | 11,569 | 318.0 |
| Arkansas | 7,344 | 9,764 | 5,263 | 334.4 | 4,379 | 2,340 | 48.1 | 18,850 | 9,464 | 504.8 | 32,993 | 17,067 | 887.3 |
| California | 1,654 | 18,093 | 9,276 | 250.2 | 14,950 | 7,430 | 14.1 | 122,651 | 60,290 | 309.6 | 155,694 | 76,996 | 573.9 |
| Colorado | 12,815 | 4,226 | 2,387 | 69.7 | 1,043 | 271 | .2 | 19,060 | 10,498 | 220.4 | 24,329 | 13,156 | 290.3 |
| Connecticut | 15,224 | 1,534 | 771 | 6.7 | 1,501 | 733 | 2.5 | 8,456 | 4,159 | 10.8 | 11,491 | 5,663 | 20.0 |
| Delaware | 3,916 | 888 | 454 | 15.4 | 2,056 | 1,034 | 4.9 | 6,419 | 3,552 | 25.7 | 9,363 | 5,040 | 46.0 |
| Florida | 4,608 | 25,684 | 13,366 | 378.7 | 5,935 | 2,981 | 61.1 | 25,185 | 12,967 | 288.9 | 56,804 | 29,314 | 728.7 |
| Georgia | 14,196 | 16,298 | 8,224 | 353.6 | 6,018 | 2,480 | 26.5 | 51,449 | 24,470 | 920.0 | 73,765 | 35,174 | 1,300.1 |
| Idaho | 1,996 | 6,335 | 4,036 | 94.2 | 5,085 | 3,337 | 112.8 | 15,277 | 9,735 | 242.0 | 26,697 | 17,108 | 449.0 |
| Illinois | 7,864 | 36,536 | 20,161 | 432.0 | 16,784 | 9,207 | 41.7 | 92,483 | 48,265 | 763.4 | 145,803 | 77,633 | 1,237.1 |
| Indiana | 11,409 | 24,904 | 13,496 | 117.4 | 14,696 | 7,375 | 76.3 | 53,268 | 27,858 | 177.3 | 92,868 | 48,729 | 371.0 |
| Iowa | 5,010 | 21,012 | 11,273 | 878.1 | 4,250 | 2,379 | 66.4 | 26,784 | 14,622 | 912.5 | 52,046 | 28,274 | 1,857.0 |
| Kansas | 7,733 | 10,543 | 5,455 | 986.1 | 4,933 | 2,494 | 132.4 | 23,857 | 11,897 | 883.6 | 39,333 | 19,846 | 2,002.1 |
| Kentucky | 5,634 | 13,196 | 6,827 | 359.6 | 8,622 | 4,710 | 70.6 | 32,435 | 16,285 | 445.0 | 54,253 | 27,822 | 875.2 |
| Louisiana | 5,185 | 12,161 | 6,080 | 107.1 | 8,493 | 4,247 | 135.0 | 39,021 | 18,386 | 378.3 | 59,675 | 28,713 | 620.4 |
| Maine | 2,009 | 10,714 | 5,649 | 89.7 | 288 | 146 | 2.4 | 16,056 | 8,259 | 129.3 | 27,058 | 14,054 | 221.4 |
| Maryland | 5,204 | 20,087 | 10,580 | 60.9 | 6,417 | 2,932 | 15.4 | 12,366 | 6,575 | 97.0 | 38,870 | 20,087 | 173.3 |
| Massachusetts | 13,953 | 6,214 | 3,097 | 23.2 | 3,687 | 1,831 | 6.6 | 49,040 | 22,931 | 51.5 | 58,941 | 27,859 | 81.3 |
| Michigan | 3,347 | 55,995 | 28,864 | 783.3 | 13,107 | 6,674 | 128.7 | 42,707 | 21,589 | 411.8 | 111,809 | 57,127 | 1,323.8 |
| Minnesota | 6,695 | 9,973 | 5,423 | 466.8 | 12,776 | 6,591 | 999.0 | 31,054 | 16,217 | 1,022.7 | 53,803 | 28,231 | 2,488.5 |
| Mississippi | 2,259 | 11,314 | 5,414 | 476.7 | 8,590 | 4,725 | 135.4 | 28,432 | 14,658 | 698.4 | 48,336 | 24,797 | 1,310.5 |
| Missouri | 8,554 | 18,270 | 9,315 | 976.7 | 3,780 | 2,092 | 18.8 | 80,551 | 41,858 | 1,456.4 | 102,601 | 53,265 | 2,451.9 |
| Montana | 9,204 | 14,535 | 9,353 | 286.8 | 3,967 | 2,405 | 148.6 | 24,910 | 15,535 | 515.4 | 43,412 | 27,293 | 950.8 |
| Nebraska | 6,426 | 22,662 | 11,746 | 1,006.5 | 9,260 | 4,337 | 161.6 | 27,534 | 15,375 | 699.4 | 59,456 | 31,458 | 1,867.5 |
| Nevada | 9,308 | 2,047 | 1,711 | 68.3 | 154 | 129 | 4.6 | 7,924 | 6,631 | 139.4 | 10,125 | 8,471 | 212.3 |
| New Hampshire | 3,690 | 4,222 | 2,111 | 27.0 | 9 | 8 | | 8,786 | 4,463 | 49.8 | 13,017 | 6,582 | 76.8 |
| New Jersey | 13,072 | 17,672 | 8,529 | 68.5 | 4,859 | 2,409 | 13.4 | 21,369 | 9,661 | 48.2 | 43,900 | 20,599 | 130.1 |
| New Mexico | 5,147 | 3,094 | 1,985 | 72.9 | 2,575 | 1,667 | 89.7 | 13,330 | 8,453 | 217.7 | 18,999 | 12,105 | 380.3 |
| New York | 30,161 | 28,670 | 15,321 | 96.9 | 50,709 | 24,459 | 91.0 | 200,644 | 94,298 | 263.7 | 280,023 | 134,078 | 451.6 |
| North Carolina | 6,767 | 23,109 | 11,367 | 424.4 | 6,455 | 3,273 | 89.3 | 41,117 | 20,103 | 575.6 | 70,681 | 34,743 | 1,089.3 |
| North Dakota | 3,326 | 7,169 | 3,622 | 1,070.6 | 10,874 | 5,384 | 782.9 | 8,787 | 4,557 | 485.9 | 26,830 | 13,563 | 2,339.4 |
| Ohio | 12,105 | 54,585 | 27,455 | 125.2 | 5,251 | 2,656 | 30.0 | 64,728 | 30,774 | 127.8 | 124,564 | 60,885 | 283.0 |
| Oklahoma | 14,677 | 5,046 | 2,615 | 182.9 | 17,130 | 8,577 | 234.5 | 25,346 | 13,415 | 365.0 | 47,522 | 24,607 | 782.4 |
| Oregon | 2,929 | 7,925 | 4,723 | 102.4 | 2,564 | 1,518 | 24.1 | 16,206 | 10,020 | 242.6 | 26,695 | 16,261 | 369.1 |
| Pennsylvania | 7,830 | 56,081 | 29,327 | 116.2 | 17,519 | 8,954 | 42.9 | 97,890 | 48,486 | 234.7 | 171,490 | 86,767 | 393.8 |
| Rhode Island | 3,047 | 5,739 | 2,869 | 13.1 | 185 | 93 | | 11,338 | 5,682 | 36.9 | 17,262 | 8,644 | 50.0 |
| South Carolina | 6,537 | 15,710 | 8,357 | 416.1 | 1,273 | 749 | 5.3 | 18,697 | 9,889 | 292.5 | 35,680 | 18,995 | 713.9 |
| South Dakota | 3,214 | 16,669 | 9,643 | 915.6 | 2,228 | 1,298 | 107.9 | 8,814 | 5,051 | 401.0 | 27,711 | 15,992 | 1,424.5 |
| Tennessee | 11,940 | 16,638 | 8,274 | 306.2 | 5,244 | 2,622 | 38.0 | 38,515 | 17,448 | 590.7 | 60,397 | 28,344 | 934.9 |
| Texas | 18,104 | 19,261 | 10,512 | 488.2 | 13,206 | 6,632 | 114.8 | 83,314 | 43,944 | 1,225.8 | 115,781 | 61,088 | 1,828.8 |
| Utah | 753 | 7,912 | 5,999 | 123.4 | 1,740 | 1,225 | 33.8 | 10,035 | 7,626 | 169.4 | 19,687 | 14,850 | 326.6 |
| Vermont | 3,394 | 917 | 463 | 14.3 | 282 | 230 | .4 | 8,823 | 4,530 | 86.7 | 10,022 | 5,223 | 101.4 |
| Virginia | 12,778 | 11,022 | 5,534 | 253.9 | 5,280 | 2,468 | 38.9 | 22,630 | 11,281 | 317.0 | 38,932 | 19,283 | 609.8 |
| Washington | 3,036 | 17,722 | 9,816 | 190.9 | 3,392 | 1,985 | 134.3 | 23,241 | 12,277 | 168.0 | 44,355 | 24,078 | 493.2 |
| West Virginia | 10,611 | 10,471 | 5,335 | 54.4 | 4,764 | 2,394 | 40.0 | 13,804 | 6,947 | 49.0 | 29,039 | 14,676 | 143.4 |
| Wisconsin | 6,937 | 16,657 | 8,275 | 328.9 | 10,563 | 5,276 | 67.8 | 39,570 | 19,827 | 542.0 | 66,790 | 33,378 | 938.7 |
| Wyoming | 989 | 4,303 | 2,788 | 89.8 | 3,168 | 2,069 | 65.6 | 13,505 | 8,670 | 292.6 | 20,976 | 13,527 | 448.0 |
| Hawaii | 3,137 | 2,426 | 1,195 | 4.4 | 2,377 | 1,183 | .8 | 5,478 | 2,452 | 12.7 | 10,281 | 4,830 | 17.9 |
| District of Columbia | 5,346 | 5,225 | 2,612 | 7.1 | 275 | 137 | .6 | 12,752 | 6,038 | 2.9 | 18,252 | 8,787 | 10.6 |
| Puerto Rico | 8,425 | 2,633 | 1,273 | 15.3 | 4,676 | 2,284 | 16.8 | 13,274 | 5,925 | 45.7 | 20,583 | 9,482 | 77.8 |
| TOTAL | 377,968 | 755,120 | 400,623 | 14,647.1 | 345,574 | 177,366 | 4,577.8 | 1,731,073 | 882,843 | 19,063.0 | 2,831,767 | 1,460,832 | 38,287.9 |

COMM-DC-46034

U. S. GOVERNMENT PRINTING OFFICE 72196